

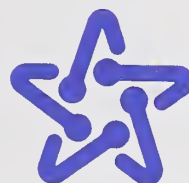
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# **TIVENESS OF HIGHWAY ARTERIAL LIGHTING**

## **Design Guide**

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**July 1977**

**Final Report**

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**Prepared for**

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**FEDERAL ENERGY ADMINISTRATION  
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Environment  
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16. Abstract <p>This research was undertaken to evaluate the cost-benefits of arterial lighting treatments in terms of traffic safety and energy use. As a result, a Design Guide has been developed to assist potential users in conducting cost-benefit analyses of lighting changes at specific locations. This Design Guide provides instructions for using a computer program to determine visibility on arterial streets and a method for conducting a cost-benefit analysis of new and upgraded lighting systems.</p> <p>In addition to this Design Guide, a Final Report (FHWA-RD-77-37) has been prepared to summarize the results of this research. The results have shown that arterial streets with high population density, in CBD areas, with low visibility have higher accident potential than arterial streets with low population density, in other areas with high visibility. Regression equations have been developed which predict dry, nighttime accident potential based on population density, area type and visibility. In addition, the results have also shown that more cost beneficial lighting systems can be designed using HPS rather than Mercury luminaires.</p>			
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## PREFACE

The investigations described in this report were conducted by the Transportation Sciences Laboratory of the Franklin Institute Research Laboratories (FIRL) under Federal Highway Administration (FHWA) contract FH-11-8825. Mr. Michael S. Janoff was the Principal Investigator for FIRL, Messrs. Richard Schwab and Paul McMahon were the Program Managers for FHWA. Ms. Shelley Launey was Program Manager for FEA.

This report in two volumes describes all of the work accomplished during the research contract. The first volume includes the following:

- A literature review covering modern lighting methods, the energy use, costs and benefits of lighting and the relationships between lighting and visibility, traffic operations, safety and crime.
- The design of instrumentation to automatically record visibility data.
- The selection of test sites, field visibility measurements at these sites and determination of accident histories at these sites.
- The analysis of accident and visibility data to develop statistical relationships between visibility and accidents.
- The development of a computer program which can (1) predict visibility based on lighting and road geometry, pavement reflectance characteristics and luminaire distributions and (2) be employed as a user oriented package for designing new lighting systems or upgrading existing systems on arterial streets.
- The development of lighting system costs for modern designs.
- The development of an economic analysis methodology for selecting new or upgraded lighting systems on arterial streets.
- The development of an optimization process which considers costs, energy use, accident or visibility improvements and design limitations as constraints in the selection of new or upgraded lighting systems for arterial streets.

- The determination of the effect of reduced or more efficient use of electric power on visibility and accidents.

The present volume contains a Design Guide which provides the lighting or traffic engineer with a handbook for:

- (1) exercising the VI prediction computer program
- (2) use of the economic/optimization process to design new or upgrade existing arterial lighting systems in urban or suburban areas.

The authors wish to thank the Philadelphia, Chester and Cheltenham township police departments for their cooperation in conducting the experiments and in addition to the above, the Philadelphia Streets Department for helping us obtain all necessary accident data. We also wish to thank Dr. Alan Sockloff, Temple University for his help in performing all the facets of the statistical analyses.

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## 1. INTRODUCTION AND BACKGROUND

The overall objective of this research was to evaluate the cost effectiveness of several selected urban and suburban highway arterial lighting treatments. Benefits evaluated included those associated with traffic safety and traffic operations. Costs included monies associated with initial installation, conversion of luminaire types, energy usage and maintenance of various lighting treatments. Figure 1 presents an overview of the research program.

### 1.1 OBJECTIVES

The program was divided into several interrelated parts, and included the following tasks:

1. Reviewed, assimilated and critically evaluated the available literature on highway arterial lighting. These included: Roadway lighting methods and specifications; roadway lighting costs, the relationship between roadway lighting and traffic operations, crime and visibility, targets for visibility studies and photometric measurement parameters, and the energy used by roadway lighting systems.
2. Developed a computer program for predicting the level of visibility provided by fixed highway illumination systems.
3. Selected test sites at which visibility was measured. These sites included examples ranging from best to worst of various illumination levels, light sources, configurations, locations, traffic and pedestrian volumes and roadway configurations. Of primary importance was both an estimate of visibility level (based on lighting and roadway geometry) and night-time accident experiences. The sites selected had at least one years' accident data and included examples ranging from high to low population densities in 3 neighborhood types (Central Business District, Outlying Business District and Residential Fringe).
4. Designed apparatus and developed a methodology for field measurement of the visibility provided by highway arterial lighting systems. Including: illumination, luminance, static and dynamic visibility and their distributions.
5. Collected and analyzed the data to relate visibility variables to nighttime accident history variables.

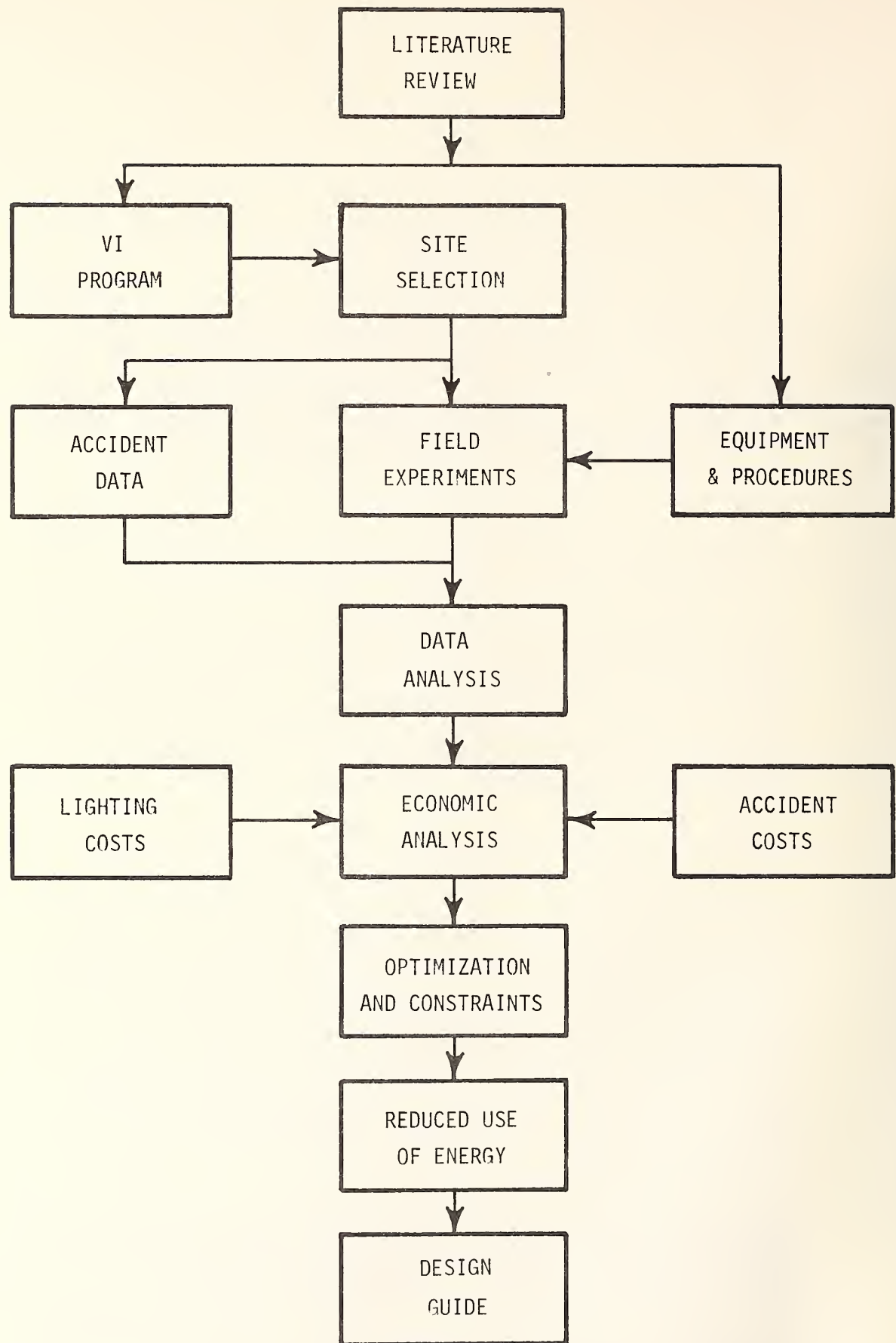


Figure 1. Overview of Research Program

6. Determined typical costs of modern arterial lighting systems - including capital, depreciation, installation, maintenance and operation (energy).
7. Developed a method of economic analysis for determining the effectiveness of arterial lighting systems based on the costs, projected accident reduction, benefit/cost ratios and other traffic flow or esthetic benefits.
8. Developed a method for determining economic/energy tradeoffs in upgrading existing systems to more effective ones - including upgrade costs, energy use (changes), benefit/cost ratios and visibility (changes).
9. Developed a method for determining optimum lighting system designs based on visibility, cost, lighting design and energy constraints.
10. Determined the impact on traffic safety of more efficient or reduced use of electricity for fixed illumination.
11. Developed a practical Design Guide which will assist traffic engineers and highway designers in designing new or upgrading existing lighting systems.

This volume contains the report on Task 11. The remainder of the tasks are covered in a separate Final Report (FHWA-RD-77-37).

## 1.2 BACKGROUND

Before reporting on the results of this program, it will be necessary to review two items which are fundamental to the understanding of the research. The first is the concept of visibility and the visibility metric derived by FIRL in past research (1), while the second is a computer program developed under this contract to predict visibility based on lighting design parameters, road geometry and pavement surface reflectance characteristics.

### 1.2.1 Visibility\*

Roadway lighting specifications are typically given as units of average flux with limits on uniformity or dispersion. Warrants are typically related to traffic, geometric and road-use conditions. The specification of lighting has undergone a long history of debate, especially as attempts are made to provide international standards. While there is much disagreement about the efficacy of certain of the warranting criteria, these criteria are generally recognized as being open for discussion and compromise. The fundamental source of disagreement is the

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\* See Reference (1) for more complete discussion of this topic.

question of flux units. Many groups responsible for setting such standards have expressed these requirements in terms of pavement luminance. Since the eye requires reflected light for the detection of objects in space, this approach is clearly related to the needs of drivers. While most scientific studies on the visual requirements of drivers have dealt in similar terms, luminance units present a complex dilemma. The basic problem is that pavement luminance is not yet easily predictable from knowledge of the distribution of flux output by the various luminaires. This is primarily due to the less-than-uniform diffusion of light reflected off paving surfaces.

The human visual-perception mechanism responds subtly to small differences in luminance intensity and exposure duration. It is fundamental that the limitations of this information-processing system must be considered in the context of the human operation under study. It is necessary, therefore, to address this problem in terms of driver information and visibility needs.

In order to determine motorists' visibility needs for the task of detecting an obstacle in the roadways, rigid control of the independent variable (visibility) is required. In addition, a precise method of measuring the responses of a large unbiased sample of motorists is essential.

FIRL developed and installed a variable intensity lighting system on an actual city street in South Philadelphia. The visibility was thus rigidly controllable over an extremely wide range(2).

Field experiments were designed and conducted at this location to determine the time-separation gap at which unalerted motorists responded evasively to a visual problem of known photometric characteristics. The basic hypothesis governing this research was that the time-separation gap characterizing the responses to low visibility targets should be highly constrained and thereby correspondingly shorter than the gap characterizing the responses to a target of higher visibility.

A method of monitoring the vehicle velocity and location was devised that permitted precise tracking of unsuspecting motorists' responses to the visual problem. The responses of over 1300 unalerted drivers under 23 conditions of task visibility were monitored and recorded electronically. The basic performance measure was target intercept time (termed Time-to-Target). This is the time-separation between vehicle and target at the point of an evasive maneuver. Figure 2 illustrates the relationship.

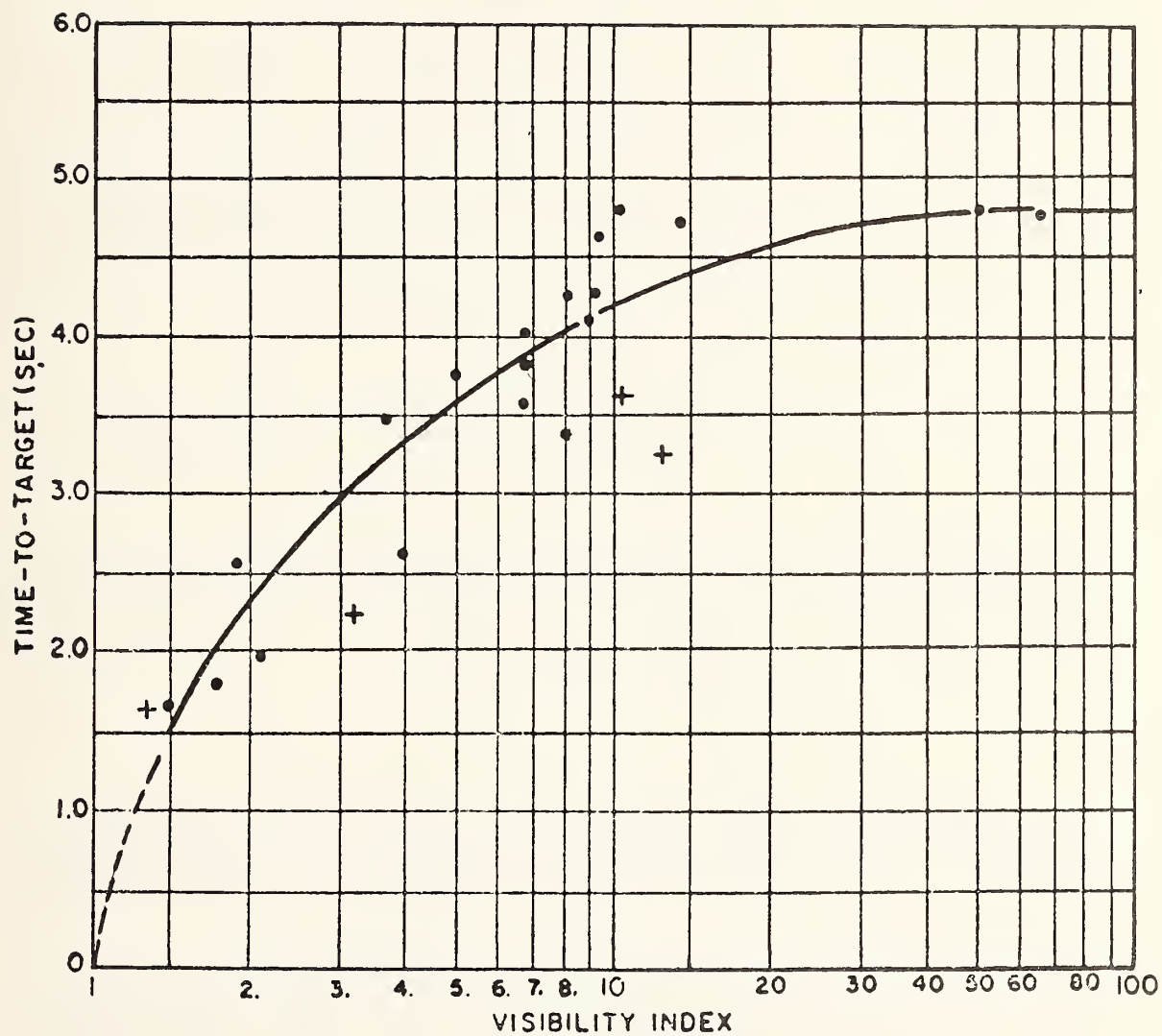


Figure 2. Regression Line for Mean Driver Responses (Raw Data) and Visibility Index

The Visibility Index used as a measure of task visibility is determined by the following expression:

$$VI = C(RCS_{Lb}) \times DGF$$

where

$$C = \text{Physical contrast} = \frac{Lt - Lb}{Lb}$$

Lt = Target Luminance; Lb = Background luminance

where

$$C = \text{Physical contrast} = \frac{\Delta L}{Lb}$$

$RCS_{Lb}$  = Relative contrast sensitivity for drivers adapted to a luminance level equal to Lb.

DGF = Disability glare factor

$$= \frac{Lb}{Lb'} \times \frac{RCS_{Lb'}}{RCS_{Lb}}$$

where

Lb' = Background luminance (Lb) plus veiling luminance (Lv) divided by a correction for sphere base glare.

The major finding was that drivers' responses to a target, photometrically quantified by the metric described, were predicted with a high degree of accuracy.

## 1.2.2 Visibility Prediction Computer Program

### 1.2.2.1 Program Description

The computer program, known as "VI", was originally developed to assist in the evaluation of existing roadway lighting systems on straight roadway sections. The program has undergone several stages of refinement and presently is capable of both evaluation and design of roadway lighting systems.

The VI program calculates horizontal and vertical illumination, (Eh and Ev) and the luminance of a target (Lt) of user specified reflectance, at each point in a roadway grid defined between two adjacent luminaires and both curb lines. For each target point, a driver's position upstream and a background area downstream are defined. Background luminance (Lb) of the roadway area which lies behind the target from a driver's line of sight, and veiling luminance (Lv) produced by each luminaire downstream of the driver are computed for each grid point. The luminance contrast (C), relative contrast sensitivity of the eye to background luminance (RCSLb), relative contrast sensitivity to background plus veiling luminance (RCSLb') a disability glare factor (DGF) and Visibility Index (VI) are calculated for the simulated driver that is

associated with each grid point. The mean, standard deviation and 15th percentile values of the grid array of each of these parameters may also be calculated as an option.

Output may be in either U.S. customary or S.I. units, depending upon input units.

The program may be employed to evaluate existing roadway lighting designs using the conventional parameters of illumination and roadway luminance and more significantly, by using the visual performance measures of glare, contrast and Visibility Index. This is the most direct application of the program. The user must specify the directional candlepower distribution of the luminaire in question, the directional reflectance distribution of the pavement and roadway and lighting system dimensions and arrangement characteristics. The relationship of these data to program operations are shown as Inputs (1.) and (2.) in Figure 3. The user may select or suppress the printing of the arrays and/or statistical summaries of any of the calculation parameters by specifying certain output option codes, identified in Input (3.) in Figure 3.

The program may be used as a design tool as well. For any combination of a particular luminance, roadway surface and roadway geometry (width, curb height, crown slope, etc.), the user may indicate a range for variation of system configuration, overhang, spacing and mounting height in Input (3.). The design option program will then generate all system combinations within those ranges and identify each of the design configurations, and their associated photometric and performance measure arrays.

#### 1.2.2.2 Program Operation

The program operates as a series of loops following the input and storage of a luminaire candlepower distribution table and a roadway directional reflectance table. In the Analysis version, the outermost loop takes successive cases from Input (2.) and Input (3.) data. For each case, the program calculates and stores an array of location coordinates for each luminaire in the system. The next inner loop defines a roadway grid, and identifies a driver, target and background location for each grid point. The innermost loop examines each location, one at a time, and calculates and sums the contribution to  $E_h$ ,  $E_v$ ,  $L_t$ ,  $L_b$ ,  $L_b'$  and  $L_v$  from each luminaire in the system. When the innermost loop is exited,  $RCSL_b$ ,  $RCSL_b'$ ,  $DGF$ ,  $C$  and  $VI$  are calculated and stored for each grid point. When the middle loop is exited, all grid points have been considered and output may be printed. Then, a new case may be read in. The design program works the same way, except that new cases are generated internally as incremental steps of overhang, mounting height, and spacing, and variations in arrangement (single side, both sides-staggered both sides-opposite) and sidedness (near, far, both).

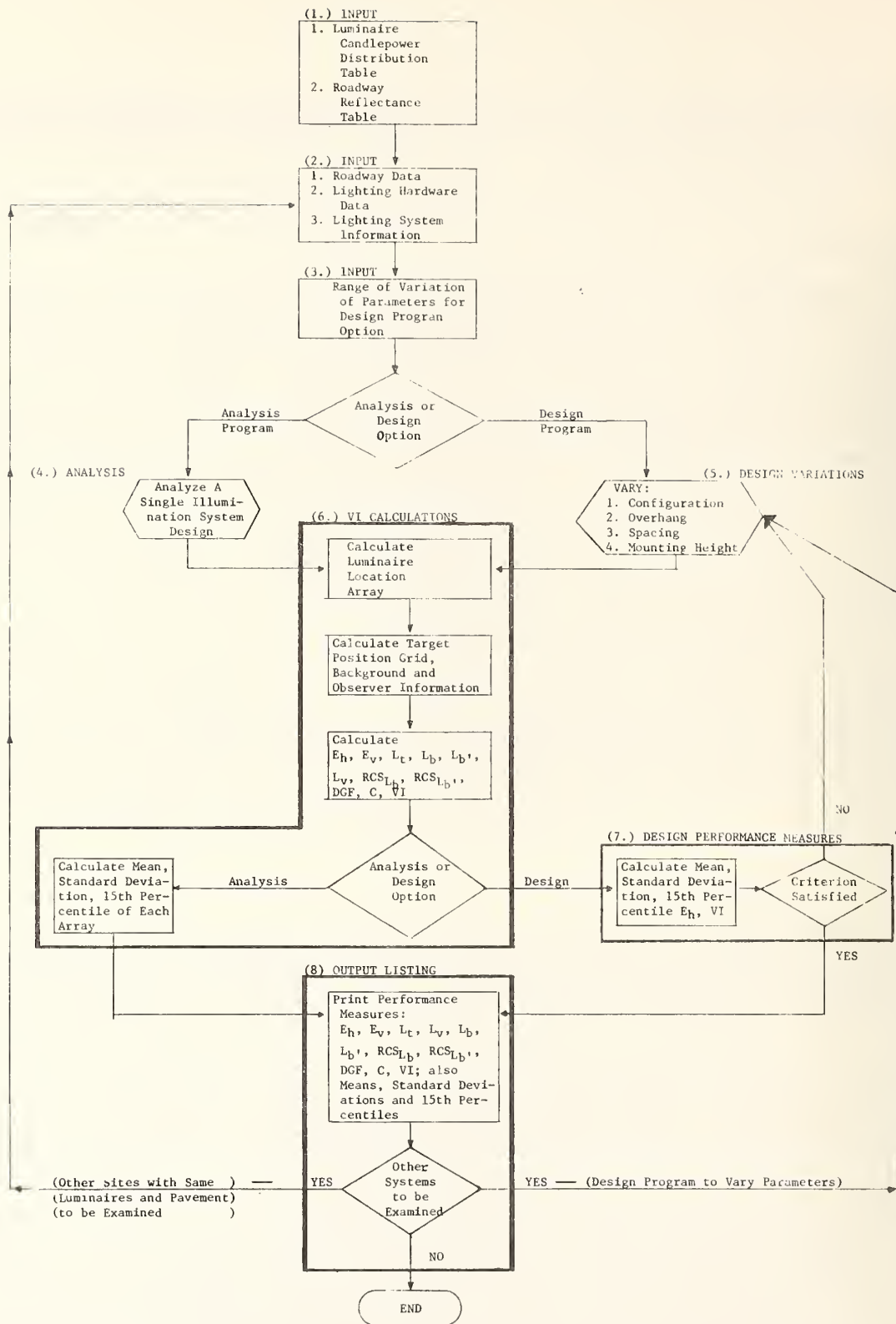


Figure 3. Block Diagram of VI Program

The program is organized as a main program, in which the photometric and performance parameters are calculated and five subroutines. The subroutines perform the functions of interpolation for candlepower and roadway reflectance, statistical calculations for mean, standard deviation and 15th percentile, output, and dump for in-depth analysis and debugging.

#### 1.2.2.3 Validation

The computer program was validated by comparison with field measurements taken on the 7th Street Lighting Test facility in Philadelphia(2). This facility is an isolated city block on which the input voltage, arrangement and sidedness of the lighted luminaires may be varied. Photometric measurements of Lt, Lb, Lv and Eh were conducted for three lighting configurations, using freshly cleaned Westinghouse OV 25 luminaires with clear mercury lamps. The configurations were:

1. 111 ft. (33.84m) spacing, both sides, opposite
2. 111 ft. (33.84m) spacing, single side, near
3. 222 ft. (67.68m) spacing, single side, near

A sample of the roadway surface was shipped to the Transport and Road Research Laboratory, Crowthorne, Berkshire, U.K., where the sample was goniometered and a table of directional reflectance factors were produced.

Comparison of computer predicted to measured parameters indicated acceptable levels of error, averaging 11% for Lt, 7% for Lb, and 12% for Lv.

The report on the research is organized into two main volumes: a final report (FHWA-RD-77-37) covering all research conducted and this volume, a Design Guide (FHWA-RD-77-38), which is provided as a self contained document, and which describes the use of the VI program and the methodology for selecting lighting on arterial streets.

This Design Guide has been developed for the engineer who is faced with the responsibility of designing new, or upgrading existing lighting systems on urban arterial streets. It provides a methodology for selecting cost-effective lighting designs and contains considerations of economic, energy, accident and design constraints that may limit the user's selection of optimal lighting designs.

This guide is structured into three distinct parts

1. Directions for use of the VI computer program.
2. Methodology for selecting lighting systems for new or unlit roadways.
3. Methodology for upgrading existing lighting systems.

## 2.0 DESCRIPTION OF VI PREDICTION PROGRAM

The computer program package which has been developed applies the concept of luminance to predict Visibility Index on arterial roadways as defined by Gallagher (1,2). In addition, the program calculates horizontal illumination ( $E_h$ ), vertical illumination ( $E_v$ ), target luminance ( $L_t$ ), background luminance ( $L_b$ ), relative contrast sensitivity (RCSLb and RCSLb'), veiling luminance ( $L_v$ ), and disability glare factor (DGF). The program can print out the values of each of these parameters for each point on a user specified grid defined within one luminaire cycle. A summary for each parameter which includes mean, standard deviation, 15th percentile VI, and three measures of uniformity (max/min, max/avg, avg/min) is also printed for all grid points not located on either curb line or the centerline of two-way streets.\*

Two options are open to the user within the structure of the VI program.

- An 'analysis' package which provides the user with a method of judging the effectiveness of the existing lighting conditions of the arterial of interest. Under this option all existing lighting hardware and roadway conditions are specified by the user and are input into the program as a single case for each arterial under consideration. The user may direct that any or all of the eleven possible output parameters are printed, which provides the user with the data to evaluate the system under consideration.
- A 'design' package which provides the user with a technique for searching out the most cost effective new system, or evaluating various upgrading options. The user specifies an initial design case, and lets the program manipulate the variables to seek out improved alternatives. The user may specify any value for  $VI_{15}$  as the lower bound visibility condition. The computer program uses this criterion to report only new design alternatives which meet or exceed that pre-specified visibility level.

### 2.1 INPUT REQUIREMENTS

The user is required to provide three basic sets of input information. These include a set of data cards which specifies the candlepower distribution of the particular luminaire/lamp combination in question, a set of data cards which specifies the directional reflectance factors

\* A copy of the VI program is on file at FHWA and at FTRL. Copies may be obtained by writing Richard N. Schwab, Environmental Design and Control Division, Federal Highway Administration, HRS-42, Washington, D.C. 20590.

of the particular roadway surface, and finally a set of four cards which identify the specific physical details of each site which will be analyzed.

The first set of data cards, for the candlepower distribution, is derived from luminaire manufacturers' specifications or goniometric testing. The data contain a value of the luminaire's candlepower at each combination of 11 vertical angles from 0 degrees (nadir) to 90 degrees (horizontal), and 21 azimuth angles from 0° (perpendicular to curbline) to 180°. The vertical angles are 0, 5, 15, 25, 35, 45, 55, 65, 75, 85 and 90 degrees. The horizontal angles are 0, 5, 15, 25, 35, 45, 55, 65, 75, 85, 90, 95, 105, 115, 125, 135, 145, 155, 165, 175 and 180 degrees.\* Decks of this type of data currently exist for a number of lamp sources (175M, 400M, 150HPS, 400HPS). Data is available for many more.

The second set of data cards, for the directional pavement reflectance values, are derived from photometric measurements of the reflective characteristics of various pavement samples.+ In essence, this table provides the factor by which the horizontal illumination from each light source which contributes to the illumination at a point on the roadway must be multiplied to determine the luminance of that roadway point as seen by a driver. A directional reflectance factor is required for each intersection of 15 vertical angles (0, 10, 20, 35, 50, 60, 65, 70, 75, 80, 82, 84, 86, 88, 90 degrees) and 37 horizontal angles (0 to 180 degrees at 5 degree increments). Twelve sets of data cards, representing various types and conditions of pavement, are presently available.

The third input requirement is a set of four cards containing the following information:

CARD 1. Fixed roadway information:	Field Length	Card Cols
• Location of study site	10A5	1-50
• Road width	F5.0	51-55
• Lane width	F4.0	56-59
• Observer to target distance	F7.2	60-66
• Crown slope	F6.4	67-72
• Curb height	F4.2	73-76

\* Other increments could be incorporated into the program with a minimum of programming effort.

+ A complete description of the derivation and measurement procedure for directional reflectance factors may be found in Reference 3.

CARD 2. System hardware and configuration data

● Mounting height	F5.1	1-5
● Spacing	F5.0	6-10
● Mast arm length	F5.1	11-15
● Pole setback	F5.1	16-20
● Luminaire type	I5	21-25
● Sideness (near, far, both)	I2	26-47
● Arrangement(single side, both opposite both staggered)	I2	28-29
● Offset distance for staggered arrangement	F6.1	30-35
● Target height	F5.2	36-40
● Observer height	F5.2	41-45
● Payment surface type	I5	46-50
● Direction of traffic operation (one-way, two-way)	I2	51-52

CARD 3. Variable calculation parameters

	Field Length	Card Columns
● Number of cycles to be considered	I5	1-5
● Number of upstream cycles	I5	6-10
● Number of downstream cycles	I5	11-15
● Number of reference luminare	I5	16-20
● Candlepower distribution correction factor(lamp life,dirt depreciation, maintenance	F6.2	21-26
● Directional reflectance correction factor(empirically determined)	F6.2	27.32
● Average target reflectance	F7.2	33-39
● 11 Selective printout codes	I-12	40-61
● Number of longitudinal roadway lines from curb to curb	I3	62-64
● Number of transverse roadway lines in the cycle	I3	65-67

CARD 4. Option 2, specified loop parameters and minimum VI <sub>15</sub>	FIELD LENGTH	CARD COLUMNS
● Option code	I1	1
● Lower bound(loop index) on mounting height	I4	2-5
● Upper bound(loop index) on mounting height	I4	6-9
● Increment of mounting height	I4	10-13
● Lower bound(loop index) on spacing	I4	14-17
● Upper bound(loop index) on spacing	I4	18-21
● Increment on spacing	I4	22-25
● Lower bound(loop index) on mast arm length	I4	26-29
● Upper bound(loop index) on mast arm length	I4	30-33
● Increment of mast arm length	I4	34-37
● Minimum VI <sub>15</sub>	F8.3	38-45
● 5 Selective configuration codes	5I3	46-60

## 2.2 INPUT DEFINITIONS

Card 1:

- Study site - any descriptive title may be specified for the particular site
- Road Width - in feet\*
- Lane Width - in feet
- Observer to target distance in feet. Standard 271.8 ft. (82.9m) is suggested based upon a driver whose eye level is 4.75 ft. (1.45m) above the roadway and whose line of sight is 1° below horizontal
- Crown slope - no units, ratio of the difference in elevation of the road surface at the curb and at the crown or center line, to the distance from curb to center line - may be estimated at 1/8 inch per foot (1cm per meter) = .0104

---

\* All units can be in U.S. Customary or SI, as long as the user is consistent.

- Curb height - in feet; may be estimated at 0.5 ft. (0.15m) for most urban streets

Card 2:

- Mounting height - distance from base of pole to luminaire height in feet
- Spacing - distance between two luminaires on the same side of the street, in feet
- Mast arm length - distance from center of pole to center of lamp in luminaire, in feet
- Pole Setback - distance from curb to center line of pole, in feet
- Luminaire type - a one digit code which identifies the luminaire type, code numbers defined by user
- Sidedness - the codes are defined at  
1 = far side, left hand side of roadway in relation to the direction of travel  
2 = near side, right hand side  
3 = both
- Arrangement - the codes are  
1 = single side  
2 = both opposite  
3 = both staggered
- Offset distance for staggered arrangement - longitudinal distance between a luminaire on one side of the roadway and the next luminaire on the opposite side of the roadway
- Target height - height, in feet, of center of target (0.25 ft. (0.08m) for spherical target for which VI is defined)
- Observer height - height, in feet, of observer (4.75 ft. (1.45m) is defined as driver eye height)
- Pavement surface type - a user specified code number identifying pavement type
- Direction of traffic - the codes are:  
1 = one way  
2 = two way

Card 3:

- Number of cycles to be considered - total number of luminaire cycles over which analysis is to be performed - 10 is usually sufficient for good accuracy. A luminaire cycle is defined as the smallest integral combination of luminaires (on one or both sides of a street) which establishes a repetitious pattern of luminaire placement. For example, in a street which has all luminaires on one side of the roadway, the total number of cycles is equal to the number of luminaires minus one ( $N-1$ ). From a point located at the same longitudinal location as one of the

luminaires, chosen for reference, there would be the same number of upstream and downstream cycles as upstream and downstream luminaires, respectively. On a street with luminaires located in a staggered arrangement on both sides of the street, a cycle is defined as the reoccurrence of a luminaire on the same side of the street as the reference luminaire from which cycles are counted.

- Number of upstream cycles - the number of cycles upstream from the luminaire which is chosen as the reference luminaire - three is usually sufficient. The upstream direction is always from the target to the observer, regardless of whether the street is one-way or two-way. On a two-way street, the upstream direction is defined opposite to the direction of travel of vehicles on the side of the street which is undergoing analysis.\*
- Number of downstream cycles - the number of cycles downstream from the reference luminaire. Seven is usually sufficient.
- Number of the reference luminaire - the sequence number assigned to the reference luminaire. Sequence is counted from upstream to downstream. This number is equal to the number of upstream cycles plus one.
- Candlepower distribution correction factor - a single number, less than one, which accounts for reduction in lumen output due to lamp life, dirt depreciation, maintenance, etc.
- Directional reflectance correction factor - a factor which is empirically determined - for FIRL sample pavement it may be set equal to 2.8. Must be determined for other surfaces.
- Average Target Reflectance - Value for standard target for research is 0.18.
- Selective printout codes - code 2 suppresses printout, code 1 commands printout of tables listing horizontal illumination, vertical illumination, target luminance, background luminance, veiling luminance,  $L_b$ , ( $L_b$  + background),  $RCSL_b'$  (Relative Contrast Sensitivity for  $L_b'$ ), luminance contrast, relative contrast sensitivity, disability glare factor, and visibility index, respectively.

---

\* A value of each of the output parameters cited in selective printout codes above, will be printed for each intersection of longitudinal and transverse roadway lines.

- Longitudinal Roadway Lines\* - imaginary lines which divide the roadway width into equal increments which are oriented parallel to the curb line. The number must be odd for two way streets; at least 3 for a one way street, and at least five for a two way street.
- Transverse Roadway Lines\* - imaginary lines which are oriented perpendicular to the curb line and divide the luminaire cycle length into equal increments.

Card 4:

- Option code - users choice, either  
1 = analysis  
2 = design
- Lower bound on mounting height - user specified minimum desired mounting height, in feet, for use in 'design' package
- Upper bound on mounting height - similarly specified maximum desired mounting height in feet
- Increment of mounting height - step size desired for iteration over minimum to maximum height, in feet
- Bounds and increments for spacing and mast length are defined the same as the mounting height
- Minimum VI15 - lower bound visibility condition in terms of VI15
- 5 Selective configuration codes - The 5 locations in the array represent the following configurations. Note, that near side is defined as the drivers right hand side, when facing the direction of the traffic flow.

#### Location

1	Single side far
2	Single side near
3	Dummy code (always = 0)
4	Both opposite
5	Both staggered

## 2.3 CONSTRAINTS ON INPUT DATA

Certain constraints exist on the input data, some of which are applicable to both options and some to a single option only.

For both options the number of longitudinal roadway lines must be odd for a two-way street; odd or even for a one-way street. There must be five or more lines for a two way street and three or more for a one

\* A value of each of the output parameters cited in selective printout codes above, will be printed for each intersection of longitudinal and transverse roadway lines.

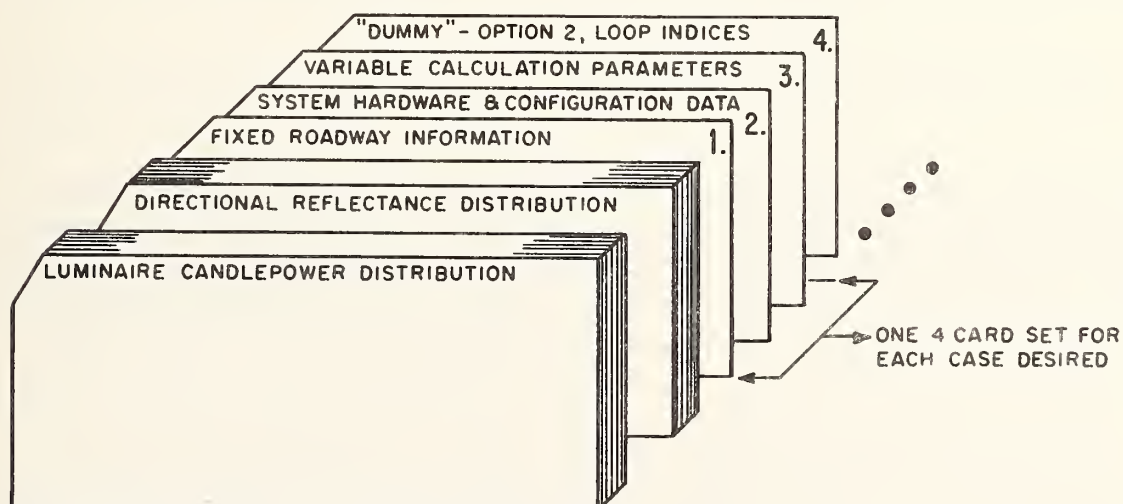
way street. All data must be entered on the data cards - blank spaces on some of the data fields will cause fatal errors. These errors may simply cause termination of a run, or they may cause an endless loop situation which would result in a very costly run.

For only the first option (analysis) the first three data cards (fixed roadway information, system hardware and configuration data, and variable calculation parameters) remain as described in the input definition section, but the fourth card with the user specified loop parameters becomes a 'dummy' card. Each data field, except the 5 selective codes, on this card must be filled in with a nominal value of *ONE*, and all others to *ZERO*.

For option two (design), modification of the system hardware and configuration data (card 2) is necessary. Since mounting height, spacing and overhang become loop parameters defined by card 4, in option two the values for these variables can be set to any number. A nominal value of *ONE* is recommended. Under option two, the configuration sidedness/arrangement) is also a loop variable. Initial values must be given to these two variables. The sidedness code must be set equal to *ONE*, and the arrangement code must be set equal to *ZERO*. *No other values are permitted.* The configuration of interest in the iterative process, can be executed by setting the appropriate location of the 5 selective codes to *ONE*. If that configuration is not desired set the location value to *ZERO*. In any event, location three must always be set to 0.

## 2.4 DATA DECK STRUCTURE

*Option 1: Analysis package*





The user has specified his data as follows. Card 1 begins with the intersection name in columns 1-50. The road width is given as 30 ft. (9.1m), with a lane width of 12 ft. (3.7m). Also given on card 1 are three more values. The first is the distance from the observer to the target, 271.82 ft. (82.8m), then the crown slope, 0.0104, and the curb height, 0.50 ft. (0.15m).

Card 2 lists the system hardware and configuration data. Taking the values left to right on the card, a mounting height of 35 ft. (10.7m), spacing, 200 ft. (61.0m), mast arm length, 7.0 ft. (2.1m) and setback of the pole from the curb of 2.0 ft. (0.6m), is specified.

The luminaire type is coded as a *ONE*, which in the example is a 400 watt Mercury lamp. The codes of *TWO* for sidedness and *ONE* for arrangement are equivalent to a near, single side, configuration. The offset is set to *ZERO* (as in this case), in all cases except a both sides staggered configuration, in which case the offset is one half the value of the spacing.

Next two heights are given. Target height is 0.25 ft. (0.08m) in this example, and observer height is 4.75 ft. (1.45m). Lastly on card 2 is the pavement type code (three in this example) and a directional code. The user has coded a one-way street.

Card 3, gives us the variable calculation parameters. Left to right again, it begins with the number of cycles in the system to be accounted for. Eleven, as is coded here, with two upstream and nine downstream (the next two values on card 3) has been tested and shown to include over 99% of the lighting contributions to the parameter values (e.g., Eh, VI, etc.). The reference luminaire is coded as number *THREE* which makes the location of the third luminaire the origin or point from which all distances are measured in the computer program.

Values for the candlepower and directional reflectance correction factor are given as 0.75 and 2.80 respectively. The next coded item is a value for average target reflectance, 0.18.

The next 11 values are output codes for the 11 parameters of interest. A code 2 is used for any parameter which printing is to be suppressed. In this example, only the eleventh parameter, VI, is of interest, and coded as a 1, to yield a printout.

The number of longitudinal and transverse line are given as 6 and 11 respectively. These numbers have been defined in an earlier section.

Card 4 in this analysis example is a 'dummy' card with option 1, specified in column 1, and nominal values of *ONE*, for all other variables, except the last four configuration codes, since none are used under option 1.

Table 1 is the resulting output after a successful run of the example case.

The output is divided into three major sections. First is a list of all input variables. Second is a matrix of parameter values for each longitudinal and transverse line intersection points. Finally the general statistical output for that parameter is printed.

Suppose now that the engineer is unsatisfied with a VII5 of 3.4781 and he wishes to upgrade his system by improving VII5. At this point the VI program allows the engineer to extrapolate new or upgraded lighting systems to compare a *change in system* to a *change in VII5*. This measure of improvement will help the engineer determine the best new or upgraded lighting system.

It is important to understand the flexibility of the VI program at this point. The engineer's original system could have been *no lighting* (VII5 = 1.00, or moonlight visibility conditions) and he may want to install a system to improve VII5 to some higher value. This *new* system he intends to install can be considered an *upgrade* also. New and upgraded systems are basically the same, although an engineer choosing a *new* system might have a great deal more leeway.

To return to the example, the engineer now makes the decision to investigate two basic upgrades. He also chooses 10.00 as the new criterion VI.\*

- (a) change the luminaire only and compare results with the criterion VI.
- (b) change some or all of the lighting system geometry variables and specify a new criterion VI to the desired level.

The first case (a), is easily taken care of by rerunning the same data set with a new luminaire candlepower distribution. Upgrade (b), requires an analysis of many cases, since several geometry variables may be involved. Here the engineer can use the 'design' version of the VI program

First he must choose his cases. Perhaps in his original case the poles were wooden and the option to raise or lower the mounting height by 10 ft. (3.0m) exists. He may also have the option of installing a new pole, between each pair to decrease the spacing to 50 ft. (15.2m), or to shut off every other luminaire and increase the spacing to 200 ft. (61.0m). Other options may also exist such as increasing the mast arm length to 13 ft. (4.0m), or changing the arrangement from single side near, to both opposite or both staggered. These cases are summarized in Table 2.

---

\* VI=10 corresponds to 85% performance as derived by Gallagher (1).

Table 1. Standard Tabular 'Analysis' Output

TEST EXAMPLE OF VI PROGRAM - ANALYSIS  
 ROAD WIDTH = 30. LANE WIDTH = 12.  
 OBSERVER-TARGET DISTANCE = 271.82  
 CROWN SLOPE = .0104 CURB HEIGHT = .50  
 MOUNTING HEIGHT = 55.0  
 SPACING = 200.  
 OVERHANG = 7.0  
 SETBACK = 2.0  
 LUMINAIRE TYPE = 1  
 SIDEWALKS = 2 ARRANGEMENT = 1  
 OFFSET = .0  
 TARGET HEIGHT = .25  
 OBSERVER HEIGHT = 4.75

11 CYCLES 2 UPSTREAM 9 DOWNSTREAM  
 .75 = CANDLEPOWER CORR FACTOR  
 2.80 = REFLECTANCE CORR FACTOR  
 .1800 = TARGET REFLECTANCE  
 1-WAY STREET  
 NO. 3 - PAVEMENT TYPE

VISIBILITY INDEX--VI

TRANS LOCN	20.0	40.0	60.0	80.0	100.0	120.0	140.0	160.0	180.0	200.0
.0	3.6441	.0824	.0470	2.5415	4.1179	6.6109	8.2179	10.1525	12.605	15.6496
6.0	3.4781	.7276	1.9852	4.0787	5.5275	7.3877	9.9024	11.5780	11.5153	3.4897
12.0	3.7890	1.7658	3.2397	4.0016	8.1365	9.5693	10.8773	12.6392	12.8852	3.8182
18.0	4.0100	1.9432	4.4313	7.3181	9.7602	11.8074	13.5418	14.2520	13.2644	4.0752
24.0	5.7804	2.8688	5.7572	8.2690	10.9908	13.0189	16.2797	13.9843	12.6553	3.8950
30.0	.5924	4.9602	7.3766	9.1811	10.8967	12.6261	15.2457	11.7548	11.4346	.5951

VI STATISTICS

MEAN = 8.1651  
 STANDARD DEVIATION = 4.4594  
 UNIFORMITY MAX/MIN = 22.3746  
 UNIFORMITY MAX/AVG = 1.9938  
 UNIFORMITY AVG/MIN = 11.2221  
 15TH PERCENTILE = 3.4781

### Table 2. Optional Cases

	Low	High	Increment Size	No. of Cases
Mounting height:	25'	45'	5'	5
Spacing:	50'	200'	50'	4
Mast arm length:	7'	13'	6'	2
Configuration: (Arrangement/ sidedness)	--	--	--	<u>3*</u> 120

$$1 \text{ ft.} = 0.3\text{m}$$

\* Single side near, both opposite, both staggered

Now that the engineer has set up his cases, the deck can be set up for his design runs. Here is how the deck will look.

CARD #4	2	25	45	5	50	200	50	7	13	6	10.000	1	0	0	1	1
CARD #3	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
CARD #2	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
CARD #1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

There are not many changes from the original case except that the type 4 card now becomes operational rather than a dummy card. As can be seen, the values of mounting height, spacing, and mast arm length on Card 2 have been set equal to *ONE* as required (columns 1-15), and the sidedness and arrangement (columns 26-29) have been set to their proper values *ONE* and *ZERO* respectively.

On the type 4 card, Option 2 is now specified. This allows us to loop over the values chosen. Also, the minimum VI15 is set at 10.00.

The user now implements his 'design' run. All 120 cases will be processed and compared against the minimum VII5 criteria, along with any other user specified criteria.

Using the 'design' version, output options are left open for the users needs. For example, the standard tabular printout (Table 1) may be executed for all cases or only those cases which satisfy the minimum VI15 criteria. A second choice might be to eliminate the standard tabular output and only include specific parameters. Table 3 displays an alternate type of output for one design case, in which the minimum VI15 = 10.00 criteria was satisfied. This specialized case only yields the geometry and parameters of interest.

Other criteria may also be specified. This other criteria may involve cost limitations. In the present example cost was not considered, only a certain level of VI15 improvement. The cost criteria might be evaluated after the results of the 'design' runs are known.

## 2.6 PROGRAM OPERATIONS

The program functions as a main program with an output subroutine and a statistical subroutine.

The logical program flow is as follows:

1. Definition of candlepower array, directional reflectance array, and basic system geometry and hardware information. Data is read in during this operation. An array of luminaire locations, in Cartesian coordinates, is then calculated.
2. Outer DO loops specifying option 2 indices which determine the number of cases to be run.
3. Middle DO loop specifying a target position and observer location coordinate set.
4. Inner DO loop calculating the contribution of each system luminaire toward roadway illumination, target luminance, background luminance, and veiling luminance. The interpolation of directional candlepower and directional reflectance is accomplished in this operation. DGF and RCS are also calculated.
5. Output and statistical routines produce matrix printouts of  $E_h$ ,  $E_v$ ,  $L_t$ ,  $L_b$ ,  $L_v$ ,  $L_b'$ ,  $RCS\ L_b'$ ,  $C$ ,  $RCS\ L_b$ ,  $DGF$  and  $VI$ , and summary statistics.

Table 3. Example of Specialized 'Design' Output

LUMIN	PAVEM	SIDE	ARRG	OVER	SPACE	N.HT.	ROAD W	LANE W	NO. DIR	OFFSET
1	3	3	2	7.0	100.0	45.0	30.0	12.0	1	.00
DOT	CROWN	CURB	T. HT.	OB. HT.	TARREF	F1	F2			
271.82	.01	.50	.25	4.75	.18	.75	2.80			

VI STATISTICS

MEAN = 16.7765  
 STANDARD DEVIATION = 1.5254  
 UNIFORMITY, MAX/MIN = 1.3415  
 UNIFORMITY, MAX/AVG = 1.1516  
 UNIFORMITY, AVG/AVG = 1.1649  
 15TH PERCENTILE = 15.0200

### 3.0 SELECTION OF LIGHTING SYSTEMS FOR NEW OR UNLIT ROADWAYS

This section, and the one that follows, present the methodology for selecting new lighting systems, or upgrading existing lighting systems on arterial streets. The process is illustrated in Figure 4 for both new (Steps 3-12) and upgraded (Steps 14-23) lighting systems.

#### 3.1 NECESSARY INPUT DATA

Before any of the subsequent methodology can be employed, the user must have certain basic inputs for each distinct roadway site describing the following environmental and geometric characteristics:

- Area Type (Central Business District or Other)
- Population Density
- Traffic Volume
- Road Width

Area type can easily be determined for a given roadway from the definition of Central Business District: "A concentration of stores, office buildings, environmental lighting, pedestrian and vehicular traffic as well as temporary on-street parking".

Population densities can be determined from census data found in most public libraries. Traffic volumes are normally available from municipal or state planning or engineering offices. Road widths are easily measured.

#### 3.2 INITIAL OPTIONS

In order to receive the most benefit from this guide, the user must first decide between two options

Option 1: If the user has data describing the candlepower distributions of the lamp/luminaire combinations he wishes to employ and has exact reflectance data for the road surfaces under consideration (both in a form suitable as input to the VI computer program described in Section 1 of this guide) then the analyses may be conducted using the VI computer program.

Option 2: If the user lacks the preceding data, or is satisfied with the range of variables presented in the FIRL data base, then he may conduct the analyses by referring to this data base, presented in Appendix A.

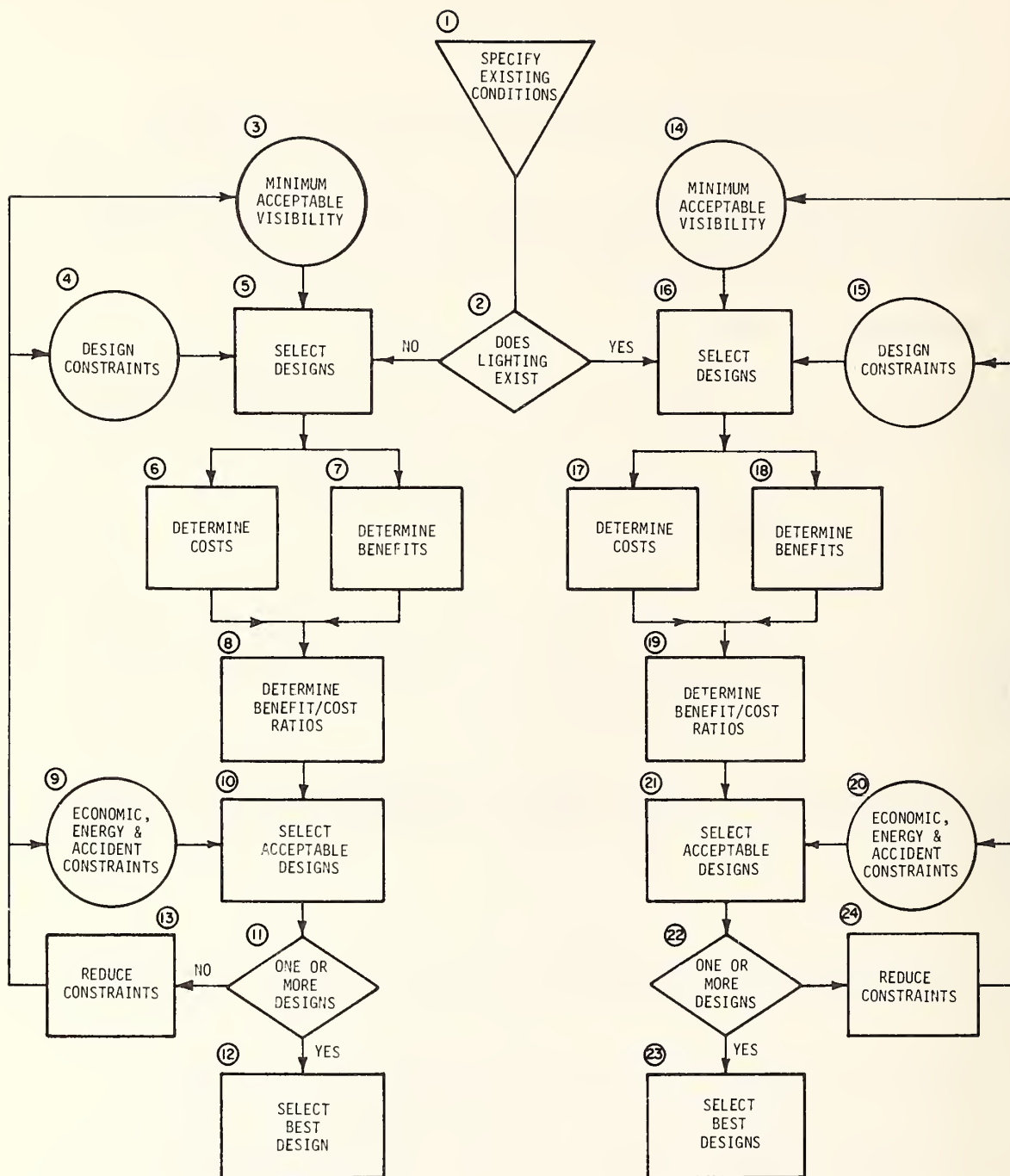


Figure 4.  
Block Diagram of Methodology for Selecting Lighting Designs

The FIRL data base defines the following roadway and lighting variables

Roadway Variables

Width: 30 ft. (9.1m); 60 ft. (18.3m)  
Directions: 1 (for 30 ft. (9.1m) road); 2 (for 60 ft. (18.3m) road)  
Surface Type: 1 (new asphalt)

Lighting Variables

Type/Size: Mercury 400 and 175\*  
HPS 400 and 150  
Arrangement: 1-sided; 2-sided opposite; 2-sided staggered  
Spacing: 50 ft.-250 ft. in 50 ft. increments (15.2m-76.2m)  
in 15.2m increments)  
Mounting Height: 20 ft.-45 ft. in 5 ft. increments (6.1m-13.7m)  
in 6.1m increments)  
Overhang: 5 ft. (1.5m) for 30 ft. (9.1m) road  
11 ft. (3.4m) for 60 ft. (18.3m) road

In addition, only traffic volumes from 5000VPD to 25,000VPD and population densities from 10,000 persons per square mile (3900 persons per square kilometer) to 60,000 persons per square mile (23,400 persons per square kilometer) are used in this data base.

### 3.3 DESCRIPTION OF THE PROCESS

The process can be broken down into an economic analysis which is based on the selection of lighting designs with the highest benefit-cost ratios, and an optimization analysis which considers constraints such as energy, accidents and economics. Figure 5 illustrates this for the part of the analysis covering new lighting designs.

#### 3.3.1 Specify Existing Conditions (Step 1)+

In this step the user merely records the existing geometric and environmental conditions on the following checklist, Figure 6.

\* Distributions

400M: Medium - Semi Cutoff - Type IV  
175M: Medium - Semi Cutoff - Type II  
400HPS: Medium - Non Cutoff - Type IV  
150HPS: Medium - Non Cutoff - Type III

+ All steps refer to the Block Diagram in Figure 5, that is an enlarged version of the left half of Figure 4 dealing with first time installations.

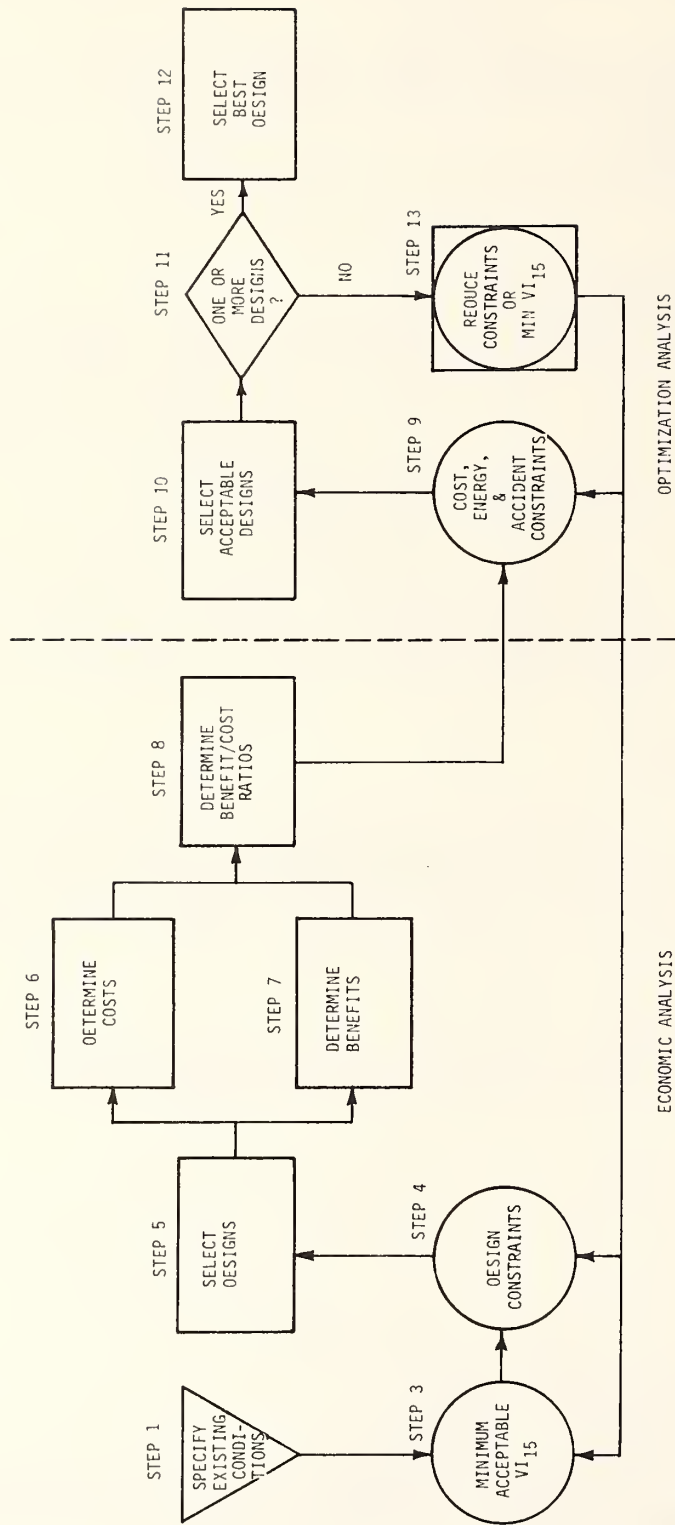


Figure 5. Methodology for New Systems

Area Type	_____
Population Density	_____
Traffic Volume	_____
Road Width	_____
Surface Type (Reflectance Table)	

Figure 6. Site Checklist

### 3.3.2 Determine Minimum Acceptable Visibility Level (Step 3)\*

The specification of a minimum acceptable visibility level is entirely up to the descretion of the user. It has been documented in the Final Report of this research that increasing the visibility on arterial streets reduces the potential for nighttime accidents.+ In addition, past research has shown that by increasing the visibility, an improvement (asymptotic near VI=15) in driver performance results (1). The prospective user may determine his minimum acceptable visibility based on either of the Final Report or Reference #1.

The selection of a minimum acceptable visibility level (VI15) at this step in the analysis is optional, and only acts to limit the number of possible system designs to those with VI15 equal to or greater than the minimum acceptable VI15. This step may be summarized into two options:

- (1) Option A - Ignore the selection of a minimum acceptable VI15 and consider all lighting system designs as possibilities.
- (2) Option B - Select a minimum acceptable VI15 and consider only those lighting system designs that provide VI15 equal to or greater than the selected VI15.

### 3.3.3 Determine Design Constraints (Step 4)

Based on the geometric and environmental conditions specified in Section 3.3.1, the user may wish to stress a particular design for his lighting system. The design constraints of a lighting system may include:

- Light Source Type, Size and Distribution
- Arrangement
- Spacing

\* Step 2, which was omitted, only determines if lighting presently exists on the site under study.

+ Final Report, FHWA-RD-77-37

- Mounting Height
- Overhang

The purpose of this step is to permit the user to specify his own design criteria to delineate only those systems that conform to those criteria. For example, design criteria may be specified in the following manner.

1. The system options must employ HPS light sources, or,
2. The lighting configuration must be staggered and the pole spacings must be no less than 100 ft. (30.5m) apart.

The design constraints outlined above are not essential to the final selection of system designs but are mentioned only to allow the user to formulate possible lighting systems based on his own preferred components.

This step therefore requires that the user specify whether or not a design constraint exists.

- No: Proceed to 3.3.4 and select lighting system designs based on minimum acceptable VII5 (if any)  
or  
Yes: Specify the constraints and proceed to 3.3.4 selecting only those systems that satisfy the design constraints and minimum acceptable VII5 (if any)

### 3.3.4 Select Possible Lighting System Designs (Step 5)

The selection of possible lighting system designs is performed in one of two ways:

1. If the user is employing the VI computer program he follows the instructions presented in Section 2 of this guide. The computer output, illustrated in Tables 1 and 3 of Section 2 would then be transferred to the form (Work Sheet number 1) provided in Table 26 of Appendix B of this guide,\* or
2. If the user is employing the FIRL data base, he reviews the entries in Table 21 of Appendix A to select those systems meeting his design and minimum visibility constraints. He then enters the systems he has selected on worksheet 1 illustrated in Table 26 of Appendix B.

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\* A complete set of worksheets is presented in Appendix B for the user employing the VI program. When completed, they will form a user generated data base for new systems.

In either of the above cases, the result is a list of possible lighting system designs which includes the complete characteristics (e.g., road geometry and lighting parameters), the visibility (VI15) provided by such a system, and a user assigned case number. An illustration is presented in Table 4.

### 3.3.5 Determine Lighting System Costs (Step 6)

Three methods for computing costs are provided in this section.

1. User provided cost data
2. FIRL provided cost data (components only)
3. FIRL Data Base

#### 3.3.5.1 User Provided Data

In the first method, the user must provide either the total annual costs per mile for every possible lighting design, or compute this figure from component costs he provides. The method is as follows.

1. Determine Number of Poles per mile (NPM)

Using the equation:

$$\begin{aligned} \text{NPM} &= \frac{5280}{\text{Spacing}} && \text{for 1-sided configurations} \\ &= \frac{5280}{\text{Spacing}} \times 2 && \text{for 2-sided configurations} \end{aligned}$$

2. Calculate Pole costs.

Multiply number of poles per mile times the cost per pole to obtain the total initial cost (P) then use the simple interest equation:

$$\text{Annual Cost} = P \frac{(1+ni)}{n} \quad \text{where}$$

n = number of years over which pole is amortized  
(user specified)

i = interest rate (user specified)

to determine the annual costs per mile. This cost should include the labor and transportation costs to install the pole.

3. Calculate luminaire costs.

This calculation is done in the same way as in number 2 above (pole costs) but with a possibly different n and with individual luminaire costs.

Table 4. VI<sub>15</sub> vs. System Descriptions

VI <sub>15</sub>	ROAD WIDTH (ft.)	LAMP/ LUMINAIRE	CONFIG- URATION	SPACING (ft.)	MOUNTING HEIGHT (ft.)	OVER- HANG (ft.)	SYSTEM CODE	CASE NO.
10.7	30	400M	STG	200	45	5	30/400M/STG/200/45/5/-	100
13.5	30	400H	SS	150	45	5	30/400H/SS/150/45/5/-	160
10.7	30	150H	SS	100	30	5	30/150H/SS/100/30/5/-	258
11.0	30	150H	SS	100	35	5	30/150H/SS/100/35/5/-	259
11.9	30	150H	STG	200	30	5	30/150H/STG/200/30/5/-	308

#### 4. Calculate Wiring Costs

The initial costs are computed as cost per linear foot (installed) x number of linear feet (5280 if 1-sided; 10,560 if 2-sided). Amortized costs are computed as in number 2 and 3 above.

#### 5. Calculate Annual Maintenance Costs

These must be user provided. They should be computed per mile of roadway.

#### 6. Calculate Annual Energy Costs per mile

This can be user provided or may be calculated using the equation:

Total Energy cost per mile = Total number of poles per mile x number of burn hours per year x number of kilowatt hours per lamp x cost per kilowatt hour.

#### 7. Calculate total costs per mile per year: sum of 2, 3, 4, 5 and 6 above and enter all appropriate figures in worksheet #2 (Table 27) of Appendix B.

### 3.3.5.2 FIRL Provided Data (Components only)

In this case, the user wishes to employ our component costs, but not total costs. This may result from a different spacing, different interest rates etc. than used in the FIRL data base. The method is the same as in Section 3.3.5.1 above, except that the component costs may be read directly from Tables 5 through 9 and then amortized following the simple interest equation presented in Section 3.3.5.1 above. Total annual costs would be computed as before and entered on worksheet number 2 (Table 27 in Appendix B).

### 3.3.5.3 FIRL Data Base

If the lighting and road parameters provided in the FIRL data base presented in Appendix A, Table 21 meet with the users specifications, then total system costs can be obtained directly from Table 22 of Appendix A. The following procedure is suggested:

1. Take the system code and case number for each selected design in Table 21 of Appendix A and locate the system in Table 22.
2. For each selected design, enter the pertinent cost data on worksheet #2 (Table 27) in Appendix B.

Table 5. Luminaire Costs\*

Type	Average Costs (\$) Per Luminaire (Installed)
Mercury	\$126
High Pressure Sodium	\$188

\*Including luminaire lamp and wiring to top connector  
(labor and material)

Table 6. Pole Costs

Type	Height <sup>(1)</sup>	Average Cost (\$) Per Pole (Installed)
Wood <sup>(2)</sup>	Low	339
	Medium	443
	High	598
Metal <sup>(3)</sup>	Low	467
	Medium	692
	High	906

- (1) Low: less than 25 ft. (7.6m); Medium: 25 ft. (7.6m) to 35 ft. (10.7m); High: over 35 ft. (10.7m)  
 (2) Including bracket arm  
 (3) Including Transformer base

Table 7. Maintenance Costs

Lamp Type	Average Costs Per Luminaire (Annual) (\$)
Mercury	7.02
HPS	23.79

Table 8. Wiring Costs

Type	Average Cost per foot (Installed) (\$)
Aerial	0.99
Underground (direct)	1.99
Underground (rigid conduit)	13.83
Underground (plastic conduit)	13.19

Table 9. Energy Costs

Item	Average Cost per Kwh (\$)
Energy	0.0248
Other*	0.0620
Total	0.0868

\* Including cost per watt demand or capacity charges, facility charges etc. See Section 6 of the Final Report for a complete description of these costs.

An example of the data is provided in Table 10. This data base covers a range of geometry values (spacing and mounting height) but is restricted to four luminaire, each with one photometric distribution. Also, only one pavement surface is included as a variable (new asphalt) of the type found on our test street in Philadelphia (3).

### 3.3.6 Determine Benefits (Step 7)

The benefits of lighting systems were developed from the regression equation\*

$$\begin{aligned} \text{Accident Rate per 10,000 vehicle miles} = & 3.61 + \\ & 7.85 \text{ (CBD vs Other)} + 0.000164(\text{Population Density}) \\ & - 0.532 \text{ (VI15)} \end{aligned}$$

where CBD vs Other is either 1 or 0 and population density is in persons per square mile.

Average accident costs were developed by the National Highway Traffic Safety Administration. This cost data provided an average cost per accident of \$2,130 and included both direct and indirect costs. This average cost has developed from the average cost per fatality, per injury and per property damage accident, weighted by frequency of each.\*

To determine the benefits of a lighting system, the following data (from Figure 6) is necessary.

Area Type (CBD or Other)  
Population Density (Persons per square mile)  
Traffic Volume (VPD)

as well as the VI15 provided by each lighting design (either generated by the user with the VI computer program, or read from Table 21 in Appendix A of the FIRL data base).

If the user desires to employ accident costs other than those presented above, he completes the worksheet #3 (Table 28 of Appendix B) using his own accident cost data and the regression equation above as follows:

1. Compute accident rate for the no-lighting condition (VI15=1) using the regression equation.
2. Compute accident rate for each lighting design using the appropriate VI15 for each design.

---

\* Discussed fully in Section 5 of the Final Report

Table 10. Costs of New Systems

SYSTEM CODE	CASE NO.	VI <sub>15</sub>	ENERGY USE (kwh/mi/yr)	INITIAL COST		ANNUAL COST		TOTAL COSTS (\$/mi/yr)
				TOTAL (\$/mi)	ANNUAL (\$/mi/yr)	ENERGY (\$/mi/yr)	MAINTEN- ANCE (\$/mi/yr)	
30/400M/STG/200/45/5/M	100	10.7	852	64038	6927	8062	398	15387
30/400H/SS/150/45/5/M	160	13.5	573	45003	4872	5374	899	11145
30/150H/SS/100/30/5/M	258	10.7	319	52294	5642	2854	1274	9769
30/150H/SS/100/35/5/M	259	11.0	319	52294	5642	2854	1274	9769
30/150H/STG/200/30/5/M	308	11.9	319	56991	5973	3022	1349	10344

3. Compute accident reduction (The difference between #1 and #2 above divided by #1)
4. Compute benefits (#3 times the average cost per accident).

If the FIRL data base is employed the user may refer directly to Table 11 for the benefits. For traffic volumes other than 10,000 VPD or high values of VI15 (greater than 15) a series of multipliers is provided at the bottom of Table 11. When using this table, values of VI15 should be rounded to the nearest whole number. To compute accident reduction (to be used subsequently) the user can employ the procedure described above (Steps 1-3) or employ the equation

$$\text{Accident Reduction} = \frac{\text{Benefits (at new VI15)} - \text{Benefits (at VI15=1)}}{\text{Benefits (at VI15=1)}}$$

### 3.3.7 Determine Benefit-Cost Ratios (Step 8)

Benefit-cost ratio is defined as the total annual benefits computed in Section 3.3.6 divided by the total annual costs computed in Section 3.3.5. For the user generating his own data, worksheet #4 (Table 29 of Appendix B) is then completed by recording the appropriate data from worksheets #2 and 3. When using the FIRL data base, Table 23 of Appendix A can be used. An example is presented in Table 12.

## 3.4 OPTIMIZATION ANALYSIS

The objective of this part of the methodology is to develop a procedure for selecting optimum lighting designs based on possible economic, energy and accident constraints.

### 3.4.1 Specify the Constraints (Step 9)

The user must specify the data in Worksheet #5 (Table 30 of Appendix B). Each entry comes from a preceding worksheet and the data is all combined here so that the user may compare alternatives based on his own applicable constraints. The data includes:

1. Lighting System Codes (From Worksheet 1)
2. Visibility (From Worksheet 1)
3. Energy Use (From Worksheet 2)
4. Lighting Costs (From Worksheet 2)
5. Site Characteristics (From Checklist - Figure 6)
6. Accident Reduction (Described in Section 3.3.6)
7. Accident Benefits (From Worksheet 3)
8. Benefit-Cost ratios (From Worksheet 4)

Table 11. Benefits of New Systems

AREA TYPE	C B D							OTHER						
	Density VI <sub>15</sub>	10,000	20,000	30,000	40,000	50,000	60,000	10,000	20,000	30,000	40,000	50,000	60,000	
1		0	0	0	0	0	0	0	0	0	0	0	0	
2		1129	1129	1129	1129	1129	1129	1129	1129	1129	1129	1129	1129	
3		2280	2280	2280	2280	2280	2280	2280	2280	2280	2280	2280	2280	
4		3409	3409	3409	3409	3409	3409	3409	3409	3409	3409	3409	3409	
5		4538	4538	4538	4538	4538	4538	4538	4538	4538	4538	4538	4538	
6		5667	5667	5667	5667	5667	5667	5667	5667	5667	5667	5667	5667	
7		6796	6796	6796	6796	6796	6796	6796	6796	6796	6796	6796	6796	
8		7947	7947	7947	7947	7947	7947	7947	7947	7947	7947	7947	7947	
9		9076	9076	9076	9076	9076	9076	9076	9076	9076	9076	9076	9076	
10		10205	10205	10205	10205	10205	10205	10054	10205	10205	10205	10205	10205	
11		11337	11337	11337	11337	11337	11337	10054	11337	11337	11337	11337	11337	
12		12471	12471	12471	12471	12471	12471	10054	12471	12471	12471	12471	12471	
13		13604	13604	13604	13604	13604	13604	10054	13549	13604	13604	13604	13604	
14		14738	14738	14738	14738	14738	14738	10054	13549	14738	14738	14738	14738	
15		15870	15870	15870	15870	15870	15870	10054	13549	15870	15870	15870	15870	

\* = Density in people  
per square mile

APPLY FACTOR FOR VOLUME CHANGE

5,000	10,000	15,000	20,000	25,000
0.5	1.0	1.5	2.0	2.5

$$\text{BENEFITS(B) for } VI_{15} > 15 = B(VI_{15}=15)(1-0.002 \times \Delta VI_{15})$$

Table 12. Benefit Cost Ratios of New Systems

SYSTEM CODE	CASE NO.	VI <sub>15</sub>	COSTS (\$/mi/yr)	AREA (TYPE)	DENSITY (People/sq mi)	VOLUME (ADT)	BENEFITS (\$/mi/yr)	BENEFIT COST RATIO
30/400M/STG/200/45/5/M	100	10.7	15387		30000	20000	22674	1.47
30/400H/SS/150/45/5/M	160	13.5	11145		30000	20000	29476	2.64
30/150H/SS/100/30/5/M	258	10.7	9767		30000	20000	22674	2.32
30/150H/SS/100/35/5/M	259	11.0	9767		30000	20000	22674	2.32
30/150H/STG/200/30/5/M	308	11.9	10344		30000	20000	24942	2.41

The derivation of each of these data has been discussed previously. Accident reduction (#6) is the only constraint whose derivation is based on area type, hence will be different for CBD and "Other" types of sites. A rough approximation of accident reduction in "Other" area types can be obtained from the accident reduction in CBD areas by multiplying the latter value by 2 (if all other environmental, geometric and lighting variables are the same). For a more exact determination, the factors illustrated in Table 13 may be employed.

At this point the user must specify his own constraints. They may take the form of budgetary limitations, maximum energy use, minimum visibility (or accident reduction) or some combination. However, all of the constraints are interactive in that an adjustment or specification of one constraint will affect the other constraints and ultimately limit the number of alternative system designs.

Table 13. Correction Factor Used to Calculate Accident Reduction for "Other" Area Types from Accident Reduction at CBD Sites

Population Density* (Persons per square mile)						
VI15	10,000	20,000	30,000	40,000	50,000	60,000
1-9	2.66	2.23	1.98	1.81	1.70	1.61
10	2.62	2.23	1.98	1.81	1.70	1.61
11	2.36	2.23	1.98	1.81	1.70	1.61
12	2.15	2.27	1.98	1.81	1.70	1.61
13	1.97	2.22	1.98	1.81	1.70	1.61
14	1.82	2.05	1.98	1.81	1.70	1.61
15	1.69	1.91	1.98	1.81	1.70	1.61

#### 3.4.2 Select Acceptable Designs (Steps 10 and 11)

The completed Worksheet #5 (Table 30 of Appendix B) will present a profile of the system characteristics with respect to all possible constraints. The user can review the completed table to identify each design which meets his constraints and then, if such designs exist, proceed to select the one with the most attractive cost-benefit ratio. If no options exist, then the user must reduce his constraints.

Table 14 presents an example of the results that would be obtained at this step.



### 3.4.3 Select Best Design (Step 12)

This step is the culmination of the optimization process if one or more system designs were isolated through the economic and optimization analysis. The best option can be defined as one with highest benefit-cost ratio which meets the design, economic, energy and accident constraints of the user.

### 3.4.4 Reduce Constraints (Step 13)

As discussed throughout this procedure, the benefit-cost ratio and the various constraints are the foundation for selecting an optimum lighting system. When constraints are set too high the result will be a paucity of acceptable options meeting those constraints. If this is the case, then it is necessary to reevaluate by reducing the constraint or perhaps selecting other luminaires. This requires repeating Steps 3, 4 or 9 and selecting another set of acceptable designs.

The options presented to the user at this step include the following:

1. Reduce minimum acceptable VI15 (Step 13)
2. Reduce design constraints (Step 4)
3. Reduce economic, energy or accident constraints (Step 9)

The process then begins again at the steps indicated above.

## 3.5 SAMPLE PROBLEMS

For the following sample problems, all data was drawn from the FIRL data base presented in Appendix A. If the prospective user employs the VI program or provides his own lighting cost or benefit data he would generate his own data base by completing the Worksheets in Appendix B.

### Example 1

#### Existing Conditions

Area Type: CBD  
Population Density: 30,000 persons per square mile (11,700  
persons per square kilometer)  
Traffic Volume: 20,000 VPD  
Road Width: 30 ft. (9.1m)  
Surface Type: New Asphalt

Minimum Acceptable VI15: 10\*

Design Constraint:

- Case 1. Use only HPS - Metal Pole
- Case 2. Use only Mercury - Metal Pole

Solutions

Case 1. HPS

Luminaire:	400 HPS	VI15: 13.5	
Arrangement:	Single Sided	Annual Costs:	\$11,145 <sup>5</sup>
Spacing:	150 ft. (45.7m)	Energy Use:	.573x10 <sup>5</sup> Kwh
Mounting Height:	45 ft. (13.7m)	B/C Ratio	2.64
Overhang:	5 ft. (1.5m)	Case #:	160

Case 2. Mercury

Luminaire:	400 M	VI15: 13.5	10.7
Arrangement:	Staggered	Annual Costs:	\$15,387 <sup>5</sup>
Spacing:	200 ft. (61.0m)	Energy Use:	0.852x10 <sup>5</sup> Kwh
Mounting Height:	45 ft. (13.7m)	B/C Ratio:	1.47
Overhang:	5 ft. (1.5m)	Case #:	100

These solutions were obtained by searching Table 24 of Appendix A for those systems with the highest Benefit/cost ratio meeting all of the constraints and input conditions.

Example 2

Area Type, Population Density, Traffic Volume, Road Width and Surface Type the same as Example 1.

Minimum Acceptable VI15:	10
Design Constraint:	Use HPS
Economic Constraint:	Total Annual Cost less than \$10,000
Energy Constraint:	Total Energy Use less than 0.5x10 <sup>5</sup> Kwh

An optimum design will be derived for each constraint separately, and then in combination. For the design constraint in conjunction with the minimum acceptable VI15 the optimum was presented in example 1.

\* About 85% of maximum performance is derived from a VI = 10. See Reference 1 for additional information

### Case 1 - Economic Constraint

For the economic constraint, the same solution will not suffice since it has total annual cost of \$11,145 per mile.

Case #258 and #259 both have VI 15 greater than 10 with annual costs less than 10,000 and both have B/C = 2.32 therefore both would suffice as solutions.

Luminaire:	150HPS	VI15:	10.7 and 11.0
Arrangement:	Single Sided	Annual Cost:	\$9759
Spacing:	100 ft.(30.5m)	Annual Energy Use:	$0.319 \times 10^5$ Kwh
Mounting Height:	30 ft. (9.1m) or 35 ft.(10.7m)	B/C ratio:	2.32
Overhang:	5 ft. (1.5m)	Case #:	258/259

### Case 2 - Energy Constraint

For the energy constraint (again in conjunction with the minimum acceptable VI15), Case #308 is the optimum.

Luminaire:	150HPS	VI15:	11.9
Arrangement:	Staggered	Annual Cost:	\$10,344
Spacing:	200 ft. (61.0m)	Annual Energy Use:	$0.139 \times 10^5$ Kwh
Mounting Height:	30 ft. (9.1m)	B/C ratio:	2.41
Overhang:	5 ft. (1.5m)	Case #:	308

In comparing the last two examples it should be noted that for the energy constraint, the optimum was selected based on maximizing the B/C ratio with annual energy less than  $0.5 \times 10^5$  Kwh/mile. For the economic constraint, the optimum was selected with maximum B/C ratio with annual costs less than \$10,000 per mile. Note that neither would suffice as optimum for the other.

### Case 3 - Combined Constraints

The optimum for this case is the same as in the example above with an economic constraint (Case 1).

The solutions for each of the preceding three cases was obtained by reviewing Table 24 of Appendix A for the system with highest B/C ratio meeting individual (or combined) constraints.

#### Example 3

##### Existing Conditions

Area Type:	CBD
Population Density:	30,000 persons per square mile (11,700 persons per square kilometer)

Traffic Volume:	20,000 VPD
Road Width:	60 ft. (18.3m)
Surface Type:	New Asphalt
Minimum Acceptable VI15:	None
Design Constraint:	None
Economic Constraint:	Total Annual Costs less than \$10,000
Energy Constraint:	Total Annual Energy Use less than 0.75x10 <sup>5</sup> Kwh

#### Optimum Solutions

##### No Constraints

Luminaire:	400HPS	VI15:	12.5/12.7
Arrangement:	Staggered	Annual Cost:	\$16,719
Spacing:	200 ft. (61.0m)	Annual Energy Use:	0.852x10 <sup>5</sup> Kwh
Mounting Height:	40 ft. (12.2m)/ 45 ft. (13.7m)	B/C ratio:	1.63
Overhang:	1 ft. (3.4m)	Case #:	139/140

##### Economic Constraint

Luminaire:	150HPS	VI15:	6.8
Arrangement:	Staggered	Annual Cost:	\$9949
Spacing:	250 ft. (76.2m)	Annual Energy Use:	0.258x10 <sup>5</sup> Kwh
Mounting Height:	40 ft. (12.2m)	B/C ratio:	1.37
Overhang:	11 ft. (3.4m)	Case #:	250

##### Energy Constraint

Luminaire:	150HPS	VI15:	13.8
Arrangement:	Staggered	Annual Cost:	\$19,540
Spacing:	100 ft. (30.5m)	Annual Energy Use:	0.639x10 <sup>5</sup> Kwh
Mounting Height:	35 ft. (10.7m)	B/C ratio:	1.51
Overhang:	11 ft. (3.4m)	Case #:	234

##### Combined Constraint

(Same as economic constraint)

## 4. UPGRADING OF EXISTING LIGHTING SYSTEMS

This section describes the methodology for upgrading existing lighting systems on arterial streets. Many of the steps and calculations described in this section and illustrated in Figure 4, Steps 14 through 23, are similar or the same as the ones described in Section 3 and illustrated in Figure 4, Steps 3 through 12. They will normally not be repeated here.

### 4.1 NECESSARY INPUT DATA

Before the methodology can be employed, the user must have certain basic input data describing the roadway geometry, existing lighting and environmental characteristics.

These include

1. Area Type
2. Population Density
3. Traffic Volume
4. Road Width
5. Description of Existing Lighting

Luminaire size, type and distribution  
Mounting Height  
Spacing  
Arrangement  
Overhang

The first four items were described in Section 3.1. The description of the lighting system should be available from the municipal or state lighting department\* or the local power company. It can be measured on-site (except for luminaire characteristics).

### 4.2 INITIAL OPTIONS

There are two options available, as described in Section 3.2

1. User provides candlepower distributions and road reflectance data, and generates his own data base using the VI program described in Section 2.
2. FIRL data base employed.

These options were described in Section 3.2

\* Sometimes called the Engineering Department, Public Works Department, Streets Department etc.

### 4.3 DESCRIPTION OF THE PROCESS

The process can be broken down into an economic analysis which is based on the selection of upgraded lighting systems with the highest benefit-cost ratios and an optimization analysis which considers constraints such as economics, energy and accidents.

The process is illustrated in Figure 7 for upgraded systems.

#### 4.3.1 Specify Existing Conditions (Step 1)\*

In this step the user records the existing geometric, environmental and lighting conditions on the following checklist, Figure 8.

All of the input data in this checklist, except VII5, is provided by the user. The specification of the VII5 provided by the existing lighting systems at each site is accomplished in one of two ways.

1. Use the roadway and lighting characteristics as input to the VI computer program and calculate VII5 for each site under analysis.
2. Refer to the FIRL data base in Table 21 of Appendix A and after locating the correct combination of arrangement/spacing/mounting height/overhang/luminaire type and size/road width, record the related visibility (VII5) as well as the existing geometric and lighting characteristics on Worksheet #6 (Table 31 in Appendix C).

#### 4.3.2 Determine Minimum Acceptable Visibility Level (Step 14)

This was fully discussed in Section 3.3.2 and will not be repeated here other than to reiterate that this step is optional and only acts to limit the number of possible upgrades to those with VII5 equal to or greater than the minimum acceptable VII5.

#### 4.3.3 Determine Design Constraints (Step 15)

Based on existing geometric, environmental and lighting conditions at each site, the user may wish to stress a particular design or preserve certain features of the existing lighting system. These constraints may include retaining (or changing) some of the existing lighting conditions based on component availability, costs, maintenance practices or energy availability. The effect is to limit the number of possible upgrades to those that meet the users own preferred criteria or specifications.

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\* All steps refer to the Block Diagram, Figure 7.

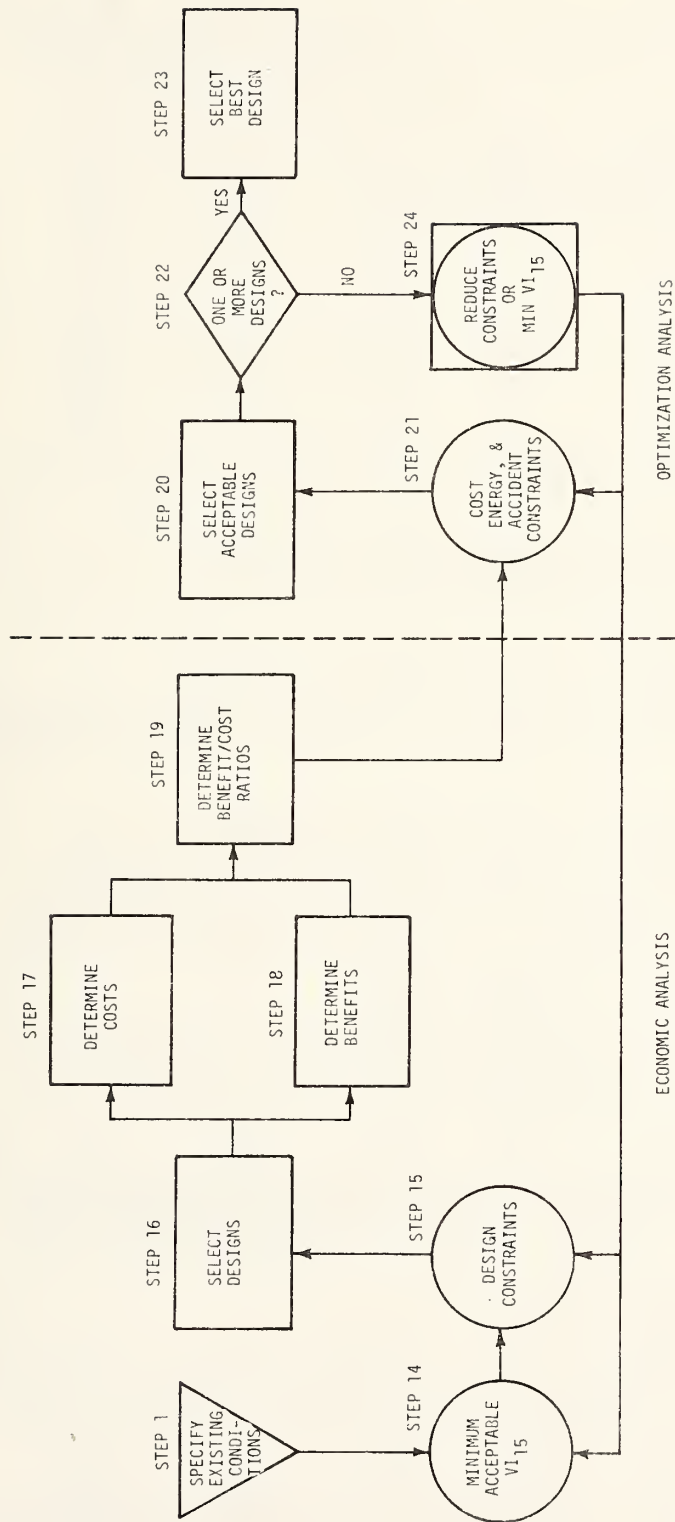


Figure 7. Methodology for Upgraded Systems

Area Type	_____
Population Density	_____
Traffic Volume	_____
Road Width	_____
Surface Type (Reflectance Table)	_____
Luminaire Size/Type/Distribution	_____
Arrangement	_____
Spacing	_____
Mounting Height	_____
Overhang	_____
Visibility (VI15)	_____

Figure 8. Site Characteristic Checklist  
for Upgraded Systems

#### 4.3.4 Select Possible Lighting System Upgrades (Step 16)

The selection of possible upgrades for each site under consideration can be accomplished in one of two ways.

1. For the user employing the VI computer program, the methods of Section 2 are used to generate possible lighting upgrades based on his own design constraints and minimum acceptable visibility. The computer output, illustrated in Tables 1 and 3 of Section 2 is then transferred to Worksheet #6 (Table 31 of Appendix C)\* or
2. For the user employing the FIRL data base, he reviews the entries in Table 21 of Appendix A to select those systems meeting his design and minimum visibility constraints.

In either of the above cases, the result is a list of possible upgrades, with complete system descriptions, visibility (VI15) and a user assigned case number. An illustration is provided in Table 15.

#### 4.3.5 Determine Upgrade Costs (Step 17)

Three methods for computing costs are provided for the prospective user.

\* A complete set of Worksheets is provided in Appendix C for upgraded systems.

Table 15 VI<sub>15</sub> vs. System Descriptions

VI <sub>15</sub>	ROAD WIDTH (ft.)	LAMP/ LUMINAIRE	CONFIG- URATION	SPACING (ft.)	MOUNTING HEIGHT (ft.)	OVER- HANG (ft.)	SYSTEM CODE	CASE NO.
4.6170	60	400M	STG	200	30	11	60/400M/STG/200/30/11/-	32
8.2351	60	400H	STG	200	30	11	60/400H/STG/200/30/11/-	137
6.2879	60	150H	STG	200	30	11	60/150H/STG/200/30/11/-	243
9.3536	60	400M	OPP	100	30	11	60/400M/OPP/100/30/11/-	2
17.7087	60	400H	OPP	100	30	11	60/400H/OPP/100/30/11/-	107
13.2493	60	150H	OPP	100	30	11	60/150H/OPP/100/30/11/-	213

#### 4.3.5.1 User Provided Data

In this first method the user must provide either the total annual increased costs per mile for each possible upgrade or at a minimum, the individual component costs, from which total increased annual costs may be computed. If individual component costs are used the steps to be followed include:

1. Determine number of new poles
2. Determine initial cost for new pole
3. Determine cost for new luminaires
4. Determine additional wiring costs
5. Determine increased maintenance costs
6. Determine increased energy/power costs
7. Calculate increased total costs per mile  
(sum of 2, 4, 4, 5 and 6 above)

All costs include labor and material for an installed item. The calculations are basically the same as those described in Section 3.3.5.1 except that

1. Only those items being changed (upgraded) are considered in the cost calculations (e.g., new luminaires or additional poles).
2. Only changes in maintenance costs or changes in energy costs are included (may be positive signifying an increase; or negative signifying a decrease).
3. Either the existing lighting system is completely paid off, in which case the costs to upgrade are the total costs, or the existing system is still being paid for and the upgrade costs are in addition to the existing costs.

#### 4.3.5.2 FIRL Provided Data (Component only)

In this case, the user will employ our component costs, presented in Tables 5 through 9 in Section 3. The method and restrictions are the same as described in Section 4.3.5.1 above, except that FIRL component costs are used.

#### 4.3.5.3 FIRL Data Base

If the lighting, road geometry and environmental conditions covered in the FIRL data base in Appendix A meet with the user specifications, then total system costs can be computed from the individual "cost per mile" figures of Table 25 in Appendix A. The method employs Worksheet #7 (Table 32 of Appendix C) and proceeds as follows:

1. Record existing system code
2. Record upgrade code
3. Record VII5 of existing system
4. Record VII5 of upgraded system

These four items are all available in Table 21 of Appendix A in the FIRL data base. The following items would be recorded from the data in Table 25 of Appendix A.

5. Energy use of existing system
6. Energy use of upgraded system
7. Initial costs of individual items in each upgraded system (e.g., luminaires, poles, wiring)
8. Annual costs of individual items, maintenance and energy
9. Total Annual Costs of each upgraded system (total of items in #8 above).

An example of this upgrade cost data is illustrated in Table 16.

#### 4.3.6 Determine Benefits (Step 18)

The calculations are almost the same as those presented in Section 3.3.6 except two calculations must be made, instead of one.

1. Benefits of existing system (Bo)
2. Benefits of Upgraded system (B1)

The actual benefits B, derived from an upgrade is determined from the equation:

$$B = B1 - Bo$$

which is positive for upgradings with higher VII5 and negative for upgradings with lower VII5.

The assumptions concerning accident rates, accident costs etc. were described in Section 3.3.6. Table 11 from that section provides the basic benefit for the user employing the FIRL data base as well as the regression equation relating accident rate to visibility which is employed if the user desires to employ his own accident cost data. In this latter case, the user will generate his own table equivalent to Table 11 by completing Worksheet #8 (Table 33 in Appendix C).

#### 4.3.7 Determine Benefit-Cost Ratios (Step 19)

As in Section 3.3.7, Benefit-cost ratio for each upgrade is computed by dividing the total annual benefits computed in Section 4.3.6 by the total annual costs computed in Section 4.3.7. Worksheet #9 (Table 34 of Appendix C) is then completed by recording the appropriate

Table 16 Costs of Upgraded Systems

[illegible]

data in Worksheets #7 and #8. An example is presented in Table 17.

#### 4.4 OPTIMIZATION ANALYSIS

The methodology is exactly the same as that presented in Section 3.4 except that the user must complete Worksheet #10 (Table 35 of Appendix C) by combining the entries from the previous four worksheets in Appendix C. Table 18 presents an example of the results obtained after completing Worksheet #10. Steps 20 through 24 of Figure 4 are identical to Steps 9 through 13 described in Sections 3.4.1 through 3.4.4 and will not be repeated. The sample problems that follow will provide examples of the methodology.

#### 4.5 SAMPLE PROBLEMS

For the following sample problems, all data was drawn from the FIRL data base in Appendix A. If the prospective user employs the VI program or provides his own lighting cost or benefit data he would generate his own data base by completing the worksheets in Appendix C.

##### Example 1

##### Existing Conditions

Area Type:	CBD
Population Density:	30,000 persons per square mile (11,700 persons per square kilometer)
Traffic Volume:	20,000 VPD
Road Width:	60 ft. (18.3m)
Surface Type:	New asphalt
Luminaire:	400M
Arrangement:	Staggered
Spacing:	200 ft. (61.0m)
Mounting Height:	30 ft. (9.1m)
Pole Type:	Metal
Overhang:	11 ft. (3.5m)
Visibility (VI15):	4.6

##### Possible Upgradings

1. 400M —→ 400HPS
2. 400M —→ 150HPS
3. 200 ft. (61.0m) —→ 100 ft. (30.5m) spacing
4. Combination of 1 and 3
5. Combination of 2 and 3

Table 18 illustrates the data described above. The optimum upgrade would be that design with highest benefit-cost ratio. It is Case 243 for this example.





## Example 2

Existing Conditions: Same as example 1.

Possible Upgradings: Same as example 1.

### Constraints:

Design: None  
Visibility: Minimum acceptable VI15 = 10  
Accident: 25% reduction  
Economic: Total increased costs less than \$2,000.  
Energy: Total energy use less than  $0.5 \times 10^5$  kwh

An optimum design will be derived for each constraint separately, then in combination.

### Combination

#### 1. Visibility

The optimum design is Case 213 with a VI15 =13.2. Case 107 has a higher VI15 (17.7) but the Benefit-cost ratio is less than 1. Similarly, Case 243 has a higher Benefit-cost ratio, but its VI15 is less than 10.

#### 2. Accident

Case 213 is optimum with a 31% accident reduction and Benefit-cost ratio = 1.13.

#### 3. Economic

Case 243 is optimum with an increased cost of \$1172 and a Benefit-cost ratio = 1.65. Case 137 is only slightly less good with a Benefit-cost ratio = 1.61.

#### 4. Energy

Case 243 is the only solution, with annual energy use =  $0.319 \times 10^5$  kwh and Benefit-cost ratio =1.65.

#### 5. Combined

There is no solution for all four constraints taken simultaneously. Case 213 will satisfy constraints 1 and 2 while Case 243 will satisfy constraints 3 and 4. No case will satisfy three constraints.

## Example 3

### Existing Conditions

Area Type

Other

Population Density:	30,000 persons per square mile (11,700 persons per square kilometer)
Traffic Volume:	20,000 VPD
Road Width:	30 ft. (9.1m)
Surface Type:	New asphalt
Luminaire:	175M
Arrangement:	Single Sided
Spacing:	200 ft. (61.0m)
Mounting Height:	25 ft. (7.6m)
Pole Type:	Wood
Overhang:	5 ft. (1.5m)
Visibility (VI15):	1.3

#### Possible Upgradings

1. 175M —————> 150HPS
2. 200 ft. (61.0m) —————> 100 ft. (30.5m) spacing
3. Combination of 1 and 2
4. 25 ft. (7.6m) —————> 30 ft. (9.1m) mounting height
5. Combination of 1 and 4

Table 19 illustrates the data described above.

The optimum upgrade would be that design with highest Benefit-cost ratio. It is Case 373 for this example.

Example 4 - Same Existing Conditions as Example 3.

#### Constraints:

Design:	Use HPS
Visibility:	None
Accident:	25% reduction
Economic:	Total increased costs less than \$2000
Energy:	Total energy use less than $0.3 \times 10^5$ kwh

An optimum design will be derived for each constraint separately, then in combination.

- |                |          |
|----------------|----------|
| 1. Design:     | Case 268 |
| 2. Visibility: | -----    |
| 3. Accident:   | Case 268 |
| 4. Economic:   | Case 268 |
| 5. Energy:     | Case 268 |
| 6. Combined:   | Case 268 |

## 4.6 EFFECT OF MORE EFFICIENT OR REDUCED USE OF ENERGY ON TRAFFIC SAFETY

As a result of recent energy shortages and energy conservation programs, many communities are seeking ways to reduce their energy

Table 19 Summary of Upgraded Systems

[illegible]

consumption. One obvious method is by using more efficient sources of illumination for roadway lighting. Others may include reducing the number or size of roadway luminaires or even the entire rebuilding of lighting systems with more efficient combinations of spacings, heights, arrangements and types of luminaires. However, before such changes are made, those responsible for system modifications should know the impact of the proposed lighting changes on visibility and traffic safety.

This section will describe how the methodology of Sections 3.4 and 4.4 (Optimization) can be applied to select lighting system upgrades with reduced or more efficient energy use and then to determine the effect of this reduction in energy use on traffic safety. The only upgraded systems that will be considered at each site will be those whose energy use is less than the existing lighting system.

#### 4.6.1 Methodology

The methodology is built around the users' completion of Worksheet #11 (Table 36 in Appendix C). The data required for this worksheet includes

1. Existing System Code
2. Reduced Energy Options
3. Case Numbers
4. Energy Use of Options
5. Energy Changes (absolute)
6. Energy Changes (%)
8. VI15 of Options
8. VI15 Changes (%)
9. Area Type
10. Density
11. Volume
12. Accident Rates
13. Changes in Accident Rates

Of the 13 items above, each reduced energy option may be user developed (e.g., using the VI program) or selected from the FIRL data base in Appendix A. In either case most of the methodology is the same as described previously. Items 1, 2, 3, 4, 7, 9, 10 and 11 were all derived from Worksheet #9. The remaining items are calculated as follows:

Energy change (#5) = Energy use of existing system - energy use of option

Energy change (#6) =  $\frac{\text{\#5}}{\text{Energy use of existing system}}$

VI15 change (#8) =  $\frac{\text{VI15 (Existing)} - \text{VI15 (Option)}}{\text{VI15 (Existing)}}$

Change in accident rate (#3) =

$$\frac{\text{Accident rate of existing system} - \text{Accident rate of option}}{\text{Accident rate of existing system}}$$

Table 20 illustrates the results which would be obtained after completing the above items.

#### 4.6.2 Sample Problems

Example 1 - Find the most energy efficient lighting option for a system consisting of:

Area Type	=	CBD
Population Density	=	30,000 persons per square mile
Traffic Value	=	20,000 VPD
Road Width	=	60 ft.
Arrangement	=	Opposite
Spacing	=	100 ft.
Mounting Height	=	30 ft.
Luminaire	=	400M

Options that will be considered include:

1. 400 —→ 150HPS
2. 100 ft. (30.5m) —→ 200 ft. (61.0m) Spacing
3. 400M —→ 400HPS plus #2
4. 400M —→ 150HPS plus #2

Table 20 provides all the relevant data required for analysis of this sample problem. The most energy efficient upgrade is Case #223 which provides an 81% reduction in energy use (saving  $1.385 \times 10^5$  kwh/mile). The effect of this change is to increase accident rate by 23%.

Example 2 - For the same system as in Case 1, find the most energy efficient upgrade that will not increase accident rate.

Case 213 provides a 63% reduction in energy use ( $1.065 \times 10^5$  kwh/mile) with an 18% decrease in accident rate.

Example 3 - Find the most energy efficient lighting option for a system consisting of:

Area Type	=	CBD
Population Density	=	30,000 persons per square mile
Traffic Volume	=	20,000 VPD
Road Width	=	30 ft.
Arrangement	=	Staggered
Spacing	=	100 ft.

Table 20 Reduced Energy Options

EXISTING SYSTEM CODE	REDUCED ENERGY OPTIONS (SYSTEM CODE)	CASE NO.	ENERGY USE (Kwh/mi/yr) (x10 <sup>2</sup> )	ENERGY CHANGE (Kwh/mi/yr)	ENERGY CHANGE (%)	V115		AREA TYPE	DENSITY (People/ Sq. Mi.)	VOLUME (ADT)	ACCIDENTS	
						UPGRADE	CHANGE (%)				NEW RATE (ac/mi/yr)	CHANGE (%)
30/400M/STG/100/30/5/M	30/400M/STG/100/30/5/M	87	1704	0	0	16.3	0	CBD	30000	20000	8.38	0
	30/150H/STG/100/30/5/M	298	639	-1065	-63	16.4	1	CBD	30000	20000	8.38	0
	30/400M/SS/100/30/5/M	47	852	-852	-50	7.4	-55	CBD	30000	20000	12.66	51
	30/400H/SS/100/30/5/M	152	852	-852	-50	15.0	-8	CBD	30000	20000	8.4	0
	30/150H/SS/100/30/5/M	258	319	-1385	-81	10.7	-34	CBD	30000	20000	10.53	26
60/400M/OPP/100/30/11/M	60/400M/OPP/100/30/11/M	2	1704	0	0	9.4	0	CBD	30000	20000	11.59	0
	60/150H/OPP/100/30/11/M	213	639	-1056	-63	13.2	40	CBD	30000	20000	9.46	-18
	60/400M/OPP/200/30/11/M	12	852	-852	-50	2.0	-79	CBD	30000	20000	15.32	32
	60/400H/OPP/200/30/11/M	117	852	-852	-50	3.0	-68	CBD	30000	20000	14.78	28
	60/150H/OPP/200/30/11/M	223	319	-1385	-81	4.2	-55	CBD	30000	20000	14.25	23

Mounting Height        = 30 ft.  
Luminaire             = 400M

Options that will be considered include:

1. 400M ———> 150HPS
2. Staggered ———> 1-sided
3. 400M ———> 400HPS plus #2
4. 400M ———> 150HPS plus #2

Table 20 provides all the relevant data for this analysis. The most energy efficient lighting system is Case 258 which provides an 81% reduction in energy use (a saving of  $1.385 \times 10^5$  kwh/mile) with an increase in accident rate of 26%.

Example 4 - For the same condition as in Example 3, find a reduced energy option which does not increase accident rate. Case 298 provides a 65% reduction in energy use ( $1.865 \times 10^5$  kwh/mile) with no increase in accident rate.

#### REFERENCES

1. Gallagher, V.P., "A Visibility Metric for Safe Lighting of City Streets", Journal of the Illuminating Engineering Society, 5(2), January 1976.
2. Gallagher, V.P., Koth, B.K., and Freedman, M., "The Specifications of Street Lighting Needs", FHWA Report No. FHWA-RD-76-17, November 1975.
3. King, L.E., "Measurement of Directional Reflectance of Pavement Surfaces and Development of Computer Techniques for Calculating Luminance", IERl-87, Final Report, Illumination Engineering Research Institute, July 1973 (unpublished draft).

## APPENDIX A

### FIRL Data Base

This appendix contains the data base generated by the VI computer program of Section 2, the regression equation of Section 3, NHTSA average accident costs and the input conditions described in Section 3 of this report. In addition, the last table provides average "per mile" costs for the components of lighting systems based on data obtained and analyzed by FIRL. The use of this data base is described in Sections 3 and 4 of this guide.

Table 21 VI<sub>15</sub> vs. System Descriptions

VI <sub>15</sub>	ROAD WIDTH (ft.)	LAMP/ LUMINAIRE	CONFIG- URATION	SPACING (ft.)	MOUNTING HEIGHT (ft.)	OVER- HANG (ft.)	SYSTEM CODE	CASE NO.
.8810	60	400M	OPP	250	25	11	60/400M/OPP/250/25/11/-	16
1.5449	60	400M	OPP	200	25	11	60/400M/OPP/200/25/11/-	11
1.6674	60	400M	OPP	250	35	11	60/400M/OPP/250/35/11/-	18
2.0309	60	400M	OPP	200	30	11	60/400M/OPP/200/30/11/-	12
2.1465	60	400M	OPP	250	30	11	60/400M/OPP/250/30/11/-	17
2.5871	60	400M	STG	250	25	11	60/400M/STG/250/25/11/-	36
2.5957	60	400M	OPP	150	25	11	60/400M/OPP/150/25/11/-	6
2.6439	60	400M	OPP	250	40	11	60/400M/OPP/250/40/11/-	19
3.1498	60	400M	STG	250	30	11	60/400M/STG/250/30/11/-	37
3.2670	60	400M	OPP	200	35	11	60/400M/OPP/200/35/11/-	13
3.4387	60	400M	OPP	250	45	11	60/400M/OPP/250/45/11/-	20
3.7183	60	400M	STG	200	25	11	60/400M/STG/200/25/11/-	31
4.3430	60	400M	STG	250	35	11	60/400M/STG/250/35/11/-	38
4.4109	60	400M	OPP	200	40	11	60/400M/OPP/200/40/11/-	14

Table 21 VI<sub>15</sub> vs. System Descriptions

VI <sub>15</sub>	ROAD WIDTH (ft.)	LAMP/ LUMINAIRE	CONFIG- URATION	SPACING (ft.)	MOUNTING HEIGHT (ft.)	OVER- HANG (ft.)	SYSTEM CODE	CASE NO.
4.6170	60	400M	STG	200	30	11	60/400M/STG/200/30/11/-	32
5.1213	60	400M	STG	250	40	11	60/400M/STG/250/40/11/-	39
5.2472	60	400M	OPP	150	30	11	60/400M/OPP/150/30/11/-	7
5.2887	60	400M	OPP	200	45	11	60/400M/OPP/200/45/11/-	15
5.5039	60	400M	STG	150	25	11	60/400M/STG/150/25/11/-	26
5.8409	60	400M	STG	250	45	11	60/400M/STG/250/45/11/-	40
6.0017	60	400M	STG	200	35	11	60/400M/STG/200/35/11/-	33
6.9845	60	400M	STG	200	40	11	60/400M/STG/200/40/11/-	34
7.1639	60	400M	OPP	150	35	11	60/400M/OPP/150/35/11/-	8
7.2646	60	400M	STG	150	30	11	60/400M/STG/150/30/11/-	27
7.6937	60	400M	OPP	100	25	11	60/400M/OPP/100/25/11/-	1
7.7776	60	400M	STG	200	45	11	60/400M/STG/200/45/11/-	35
7.9566	60	400M	OPP	150	40	11	60/400M/OPP/150/40/11/-	9
8.3169	60	400M	OPP	150	45	11	60/400M/OPP/150/45/11/-	10

Table 21 VI<sub>15</sub> vs. System Descriptions

VI <sub>15</sub>	ROAD WIDTH (ft.)	LAMP/ LUMINAIRE	CONFIG- URATION	SPACING (ft.)	MOUNTING HEIGHT (ft.)	OVER- HANG (ft.)	SYSTEM CODE	CASE NO.
8.9928	60	400M	STG	150	35	11	60/400M/STG/150/35/11/-	28
9.3536	60	400M	OPP	100	30	11	60/400M/OPP/100/30/11/-	2
9.9268	60	400M	STG	150	40	11	60/400M/STG/150/40/11/-	29
10.5406	60	400M	STG	100	25	11	60/400M/STG/100/25/11/-	21
10.6611	60	400M	STG	150	45	11	60/400M/STG/150/45/11/-	30
10.9258	60	400M	OPP	100	35	11	60/400M/OPP/100/35/11/-	3
11.8463	60	400M	OPP	100	40	11	60/400M/OPP/100/40/11/-	4
12.4308	60	400M	STG	100	30	11	60/400M/STG/100/30/11/-	22
12.6741	60	400M	OPP	100	45	11	60/400M/OPP/100/45/11/-	5
13.3502	60	400M	STG	100	35	11	60/400M/STG/100/35/11/-	23
13.7586	60	400M	STG	100	40	11	60/400M/STG/100/40/11/-	24
13.8469	60	400M	STG	100	45	11	60/400M/STG/100/45/11/-	25

Table 21 VI<sub>15</sub> vs. System Descriptions

VI <sub>15</sub>	ROAD WIDTH (ft.)	LAMP/ LUMINAIRE	CONFIG- URATION	SPACING (ft.)	MOUNTING HEIGHT (ft.)	OVER- HANG (ft.)	SYSTEM CODE	CASE NO.
.8994	30	400M	SS	250	25	5	30/400M/SS/250/25/5/-	61
1.1146	30	400M	OPP	250	25	5	30/400M/OPP/250/25/5/-	81
1.1876	30	400M	SS	250	30	5	30/400M/SS/250/30/5/-	62
1.2269	30	400M	SS	200	25	5	30/400M/SS/200/25/5/-	56
1.5359	30	400M	SS	250	35	5	30/400M/SS/250/35/5/-	63
1.6293	30	400M	OPP	200	25	5	30/400M/OPP/200/25/5/-	76
1.6937	30	400M	OPP	250	30	5	30/400M/OPP/250/30/5/-	82
2.0427	30	400M	SS	200	30	5	30/400M/SS/200/30/5/-	57
2.6482	30	400M	OPP	250	35	5	30/400M/OPP/250/35/5/-	83
2.9871	30	400M	SS	150	25	5	30/400M/SS/150/25/5/-	51
3.0416	30	400M	SS	250	40	5	30/400M/SS/250/40/5/-	64
3.0849	30	400M	STG	250	25	5	30/400M/STG/250/25/5/-	101.
3.1334	30	400M	OPP	200	30	5	30/400M/OPP/200/30/5/-	77
3.4781	30	400M	SS	200	35	5	30/400M/SS/200/35/5/-	58.

Table 21 VI<sub>15</sub> vs. System Descriptions

VI <sub>15</sub>	ROAD WIDTH (ft.)	LAMP/ LUMINAIRE	CONFIG- URATION	SPACING (ft.)	MOUNTING HEIGHT (ft.)	OVER- HANG (ft.)	SYSTEM CODE	CASE NO.
3.8717	30	400M	SS	250	45	5	30/400M/SS/250/45/5/-	65
4.0851	30	400M	OPP	150	25	5	30/400M/OPP/150/25/5/-	71
4.1406	30	400M	OPP	250	40	5	30/400M/OPP/250/40/5/-	84
4.2786	30	400M	SS	150	30	5	30/400M/SS/150/30/5/-	52
4.4390	30	400M	SS	200	40	5	30/400M/SS/200/40/5/-	59
4.8560	30	400M	STG	200	25	5	30/400M/STG/200/25/5/-	96
5.0597	30	400M	STG	250	30	5	30/400M/STG/250/30/5/-	102
5.1208	30	400M	OPP	200	35	5	30/400M/OPP/200/35/5/-	78
5.2257	30	400M	OPP	250	45	5	30/400M/OPP/250/45/5/-	85
5.2838	30	400M	SS	200	45	5	30/400M/SS/200/45/5/-	60
5.6499	30	400M	SS	100	25	5	30/400M/SS/100/25/5/-	46
5.6875	30	400M	SS	150	35	5	30/400M/SS/150/35/5/-	53
6.2159	30	400M	STG	250	35	5	30/400M/STG/250/35/5/-	103
6.5010	30	400M	SS	150	40	5	30/400M/SS/150/40/5/-	54

Table 21 - VI<sub>15</sub> vs. System Descriptions

VI <sub>15</sub>	ROAD WIDTH (ft.)	LAMP/ LUMINAIRE	CONFIG- URATION	SPACING (ft.)	MOUNTING HEIGHT (ft.)	OVER- HANG (ft.)	SYSTEM CODE	CASE NO.
6.8327	30	400M	OPP	200	40	5	30/400M/OPP/200/40/5/-	79
6.9250	30	400M	STG	200	30	5	30/400M/STG/200/30/5/-	97
6.9667	30	400M	OPP	150	30	5	30/400M/OPP/150/30/5/-	72
7.2100	30	400M	STG	250	40	5	30/400M/STG/250/40/5/-	104
7.2532	30	400M	SS	150	45	5	30/400M/SS/150/45/5/-	55
7.3615	30	400M	SS	100	30	5	30/400M/SS/100/30/5/-	47
7.4271	30	400M	OPP	200	45	5	30/400M/OPP/200/45/5/-	80
8.2765	30	400M	STG	250	45	5	30/400M/STG/250/45/5/-	105
8.7721	30	400M	OPP	150	35	5	30/400M/OPP/150/35/5/-	73
8.8052	30	400M	STG	150	25	5	30/400M/STG/150/25/5/-	91
8.9787	30	400M	STG	200	35	5	30/400M/STG/200/35/5/-	98
9.0578	30	400M	SS	100	35	5	30/400M/SS/100/35/5/-	48
9.5703	30	400M	SS	100	40	5	30/400M/SS/100/40/5/-	49
9.8049	30	400M	SS	100	45	5	30/400M/SS/100/45/5/-	50

Table 21 VI<sub>15</sub> vs. System Descriptions

VI <sub>15</sub>	ROAD WIDTH (ft.)	LAMP/ LUMINAIRE	CONFIG- URATION	SPACING (ft.)	MOUNTING HEIGHT (ft.)	OVER- HANG (ft.)	SYSTEM CODE	CASE NO.
9.9145	30	400M	OPP	150	40	5	30/400M/OPP/150/40/5/-	74
10.0520	30	400M	STG	200	40	5	30/400M/STG/200/40/5/-	99
10.7445	30	400M	STG	200	45	5	30/400M/STG/200/45/5/-	100
10.7561	30	400M	OPP	150	45	5	30/400M/OPP/150/45/5/-	75
10.9366	30	400M	OPP	100	25	5	30/400M/OPP/100/25/5/-	66
11.0322	30	400M	STG	150	30	5	30/400M/STG/150/30/5/-	92
11.1383	30	400M	SS	50	25	5	30/400M/SS/50/25/5/-	41
12.2305	30	400M	SS	50	30	5	30/400M/SS/50/30/5/-	42
12.2712	30	400M	STG	150	35	5	30/400M/STG/150/35/5/-	93
12.7652	30	400M	OPP	100	30	5	30/400M/OPP/100/30/5/-	67
12.9781	30	400M	STG	150	40	5	30/400M/STG/150/40/5/-	94
13.0730	30	400M	SS	50	35	5	30/400M/SS/50/35/5/-	43
13.1876	30	400M	STG	150	45	5	30/400M/STG/150/45/5/-	95
13.8569	30	400M	SS	50	40	5	30/400M/SS/50/40/5/-	44

Table 21 VI<sub>15</sub> vs. System Descriptions

VI <sub>15</sub>	ROAD WIDTH (ft.)	LAMP/ LUMINAIRE	CONFIG- URATION	SPACING (ft.)	MOUNTING HEIGHT (ft.)	OVER- HANG (ft.)	SYSTEM CODE	CASE NO.
13.9885	30	400M	OPP	100	35	5	30/400M/OPP/100/35/5/-	68
14.1075	30	400M	SS	50	45	5	30/400M/SS/50/45/5/-	45
14.7439	30	400M	OPP	100	40	5	30/400M/OPP/100/40/5/-	69
15.2114	30	400M	STG	100	25	5	30/400M/STG/100/25/5/-	86
15.4200	30	400M	OPP	100	45	5	30/400M/OPP/100/45/5/-	70
16.2451	30	400M	STG	100	45	5	30/400M/STG/100/45/5/-	90
16.3119	30	400M	STG	100	35	5	30/400M/STG/100/35/5/-	88
16.3251	30	400M	STG	100	40	5	30/400M/STG/100/40/5/-	89
16.3397	30	400M	STG	100	30	5	30/400M/STG/100/30/5/-	87

Table 21 VI<sub>15</sub> vs. System Descriptions

VI <sub>15</sub>	ROAD WIDTH (ft.)	LAMP/ LUMINAIRE	CONFIG- URATION	SPACING (ft.)	MOUNTING HEIGHT (ft.)	OVER- HANG (ft.)	SYSTEM CODE	CASE NO.
1.2712	60	400H	OPP	250	25	11	60/400H/OPP/250/25/11/-	121
2.1290	60	400H	OPP	200	25	11	60/400H/OPP/200/25/11/-	116
2.1435	60	400H	OPP	250	35	11	60/400H/OPP/250/35/11/-	123
2.9904	60	400H	OPP	200	30	11	60/400H/OPP/200/30/11/-	117
3.0037	60	400H	OPP	250	30	11	60/400H/OPP/250/30/11/-	122
3.6696	60	400H	OPP	250	40	11	60/400H/OPP/250/40/11/-	124
4.5323	60	400H	STG	200	25	11	60/400H/STG/200/25/11/-	136
5.1070	60	400H	OPP	250	45	11	60/400H/OPP/250/45/11/-	135
5.2690	60	400H	STG	250	25	11	60/400H/STG/250/25/11/-	141
5.5971	60	400H	STG	250	30	11	60/400H/STG/250/30/11/-	142
5.7963	60	400H	OPP	200	35	11	60/400H/OPP/200/35/11/-	118
6.1494	60	400H	OPP	150	25	11	60/400H/OPP/150/25/11/-	111
8.1186	60	400H	STG	250	35	11	60/400H/STG/250/35/11/-	143
8.2351	60	400H	STG	200	30	11	60/400H/STG/200/30/11/-	137

Table 21 VI<sub>15</sub> vs. System Descriptions

VI <sub>15</sub>	ROAD WIDTH (ft.)	LAMP/ LUMINAIRE	CONFIG- URATION	SPACING (ft.)	MOUNTING HEIGHT (ft.)	OVER- HANG (ft.)	SYSTEM CODE	CASE NO.
8.4780	60	400H	OPP	200	40	11	60/400H/OPP/200/40/11/-	119
9.3078	60	400H	STG	250	40	11	60/400H/STG/250/40/11/-	144
9.9797	60	400H	STG	150	25	11	60/400H/STG/150/25/11/-	131
10.0443	60	400H	OPP	150	30	11	60/400H/OPP/150/30/11/-	112
10.3950	60	400H	OPP	200	45	11	60/400H/OPP/200/45/11/-	120
10.8254	60	400H	STG	250	45	11	60/400H/STG/250/45/11/-	145
10.8731	60	400H	STG	200	35	11	60/400H/STG/200/35/11/-	138
12.5312	60	400H	STG	200	40	11	60/400H/STG/200/40/11/-	139
12.6462	60	400H	OPP	150	35	11	60/400H/OPP/150/35/11/-	113
12.6517	60	400H	STG	200	45	11	60/400H/STG/200/45/11/-	140
13.1234	60	400H	STG	150	30	11	60/400H/STG/150/30/11/-	132
13.9072	60	400H	OPP	150	40	11	60/400H/OPP/150/40/11/-	114
14.1990	60	400H	STG	150	35	11	60/400H/STG/150/35/11/-	133
14.7243	60	400H	OPP	150	45	11	60/400H/OPP/150/45/11/-	115

Table 21 VI<sub>15</sub> vs. System Descriptions

VI <sub>15</sub>	ROAD WIDTH (ft.)	LAMP/ LUMINAIRE	CONFIG- URATION	SPACING (ft.)	MOUNTING HEIGHT (ft.)	OVER- HANG (ft.)	SYSTEM CODE	CASE NO.
14.9777	60	400H	STG	150	40	11	60/400H/STG/150/40/11/-	134
15.4985	60	400H	STG	150	45	11	60/400H/STG/150/45/11/-	135
15.9305	60	400H	OPP	100	25	11	60/400H/OPP/100/25/11/-	106
16.4778	60	400H	STG	100	25	11	60/400H/STG/100/25/11/-	126
17.7087	60	400H	OPP	100	30	11	60/400H/OPP/100/30/11/-	107
17.7477	60	400H	STG	100	35	11	60/400H/STG/100/35/11/-	108
17.9885	60	400H	OPP	100	45	11	60/400H/OPP/100/45/11/-	110
18.0474	60	400H	OPP	100	40	11	60/400H/OPP/100/40/11/-	109
18.2482	60	400H	STG	100	40	11	60/400H/STG/100/40/11/-	129
18.3634	60	400H	STG	100	35	11	60/400H/STG/100/35/11/-	128
18.4662	60	400H	STG	100	45	11	60/400H/STG/100/45/11/-	130
19.0943	60	400H	STG	100	30	11	60/400H/STG/100/30/11/-	127

Table 21 VI<sub>15</sub> vs. System Descriptions

VI <sub>15</sub>	ROAD WIDTH (ft.)	LAMP/ LUMINAIRE	CONFIG- URATION	SPACING (ft.)	MOUNTING HEIGHT (ft.)	OVER- HANG (ft.)	SYSTEM CODE	CASE NO.
1.5257	30	400H	SS	250	25	5	30/400H/SS/250/25/5/-	166
1.8018	30	400H	OPP	200	30	5	30/400H/OPP/200/30/5/-	182
1.8576	30	400H	OPP	250	35	5	30/400H/OPP/250/35/5/-	188
1.9407	30	400H	SS	200	25	5	30/400H/SS/200/25/5/-	161
2.4167	30	400H	SS	250	30	5	30/400H/SS/250/30/5/-	167
3.0280	30	400H	SS	250	35	5	30/400H/SS/250/35/5/-	168
3.3389	30	400H	OPP	250	25	5	30/400H/OPP/250/25/5/-	186
3.8013	30	400H	SS	250	40	5	30/400H/SS/250/40/5/-	169
3.9129	30	400H	OPP	250	40	5	30/400H/OPP/250/40/5/-	189
4.1931	30	400H	OPP	250	30	5	30/400H/OPP/250/30/5/-	187
4.2644	30	400H	SS	200	30	5	30/400H/SS/200/30/5/-	162
5.4187	30	400H	OPP	200	30	5	30/400H/OPP/200/25/5/-	181
5.7869	30	400H	SS	250	45	5	30/400H/SS/250/45/5/-	170
6.1355	30	400H	SS	150	25	5	30/400H/SS/150/25/5/-	156

Table 21 VI<sub>15</sub> vs. System Descriptions

VI <sub>15</sub>	ROAD WIDTH (ft.)	LAMP/ LUMINAIRE	CONFIG- URATION	SPACING (ft.)	MOUNTING HEIGHT (ft.)	OVER- HANG (ft.)	SYSTEM CODE	CASE NO.
6.2292	30	400H	SS	200	35	5	30/400H/SS/200/35/5/-	163
6.3377	30	400H	OPP	200	35	5	30/400H/OPP/200/35/5/-	183
6.7666	30	400H	OPP	250	45	5	30/400H/OPP/250/45/5/-	190
7.2024	30	400H	OPP	150	25	5	30/400H/OPP/150/25/5/-	176
7.2805	30	400H	STG	250	25	5	30/400H/STG/250/25/5/-	206
8.1196	30	400H	SS	200	40	5	30/400H/SS/200/40/5/-	164
9.4998	30	400H	SS	200	45	5	30/400H/SS/200/45/5/-	165
9.7858	30	400H	SS	150	30	5	30/400H/SS/150/30/5/-	157
10.1254	30	400H	OPP	200	40	5	30/400H/OPP/200/40/5/-	184
11.4511	30	400H	SS	150	35	5	30/400H/SS/150/35/5/-	158
11.9274	30	400H	STG	250	30	5	30/400H/STG/250/30/5/-	207
12.4292	30	400H	OPP	200	45	5	30/400H/OPP/200/45/5/-	185
12.8010	30	400H	OPP	150	30	5	30/400H/OPP/150/30/5/-	177
12.9086	30	400H	STG	200	25	5	30/400H/STG/200/25/5/-	201

Table 21 VI<sub>15</sub> vs. System Descriptions

VI <sub>15</sub>	ROAD WIDTH (ft.)	LAMP/ LUMINAIRE	CONFIG- URATION	SPACING (ft.)	MOUNTING HEIGHT (ft.)	OVER- HANG (ft.)	SYSTEM CODE	CASE NO.
12.9175	30	400H	SS	150	40	5	30/400H/SS/150/40/5/-	159
12.9967	30	400H	SS	100	25	5	30/400H/SS/100/25/5/-	151
13.5056	30	400H	SS	150	45	5	30/400H/SS/150/45/5/-	160
13.8159	30	400H	STG	250	35	5	30/400H/STG/250/35/5/-	208
14.6652	30	400H	STG	250	40	5	30/400H/STG/250/40/5/-	209
14.9865	30	400H	SS	100	30	5	30/400H/SS/100/30/5/-	152
15.2541	30	400H	STG	250	45	5	30/400H/STG/250/45/5/-	210
15.9288	30	400H	OPP	150	35	5	30/400H/OPP/150/35/5/-	178
15.9360	30	400H	STG	200	30	5	30/400H/STG/200/30/5/-	202
16.5757	30	400H	SS	100	35	5	30/400H/SS/100/35/5/-	153
16.7189	30	400H	STG	200	35	5	30/400H/STG/200/35/5/-	203
16.8209	30	400H	STG	200	40	5	30/400H/STG/200/40/5/-	204
16.8975	30	400H	SS	100	40	5	30/400H/SS/100/40/5/-	154
16.9996	30	400H	STG	200	45	5	30/400H/STG/200/45/5/-	205

Table 21 VI<sub>15</sub> vs. System Descriptions

VI <sub>15</sub>	ROAD WIDTH (ft.)	LAMP/ LUMINAIRE	CONFIG- URATION	SPACING (ft.)	MOUNTING HEIGHT (ft.)	OVER- HANG (ft.)	SYSTEM CODE	CASE NO.
17.1444	30	400H	SS	100	45	5	30/400H/SS/100/45/5/-	155
17.4568	30	400H	OPP	150	40	5	30/400H/OPP/150/40/5/-	179
17.8687	30	400H	OPP	150	45	5	30/400H/OPP/150/45/5/-	180
19.4175	30	400H	STG	150	25	5	30/400H/STG/150/25/5/-	196
20.1938	30	400H	STG	150	30	5	30/400H/STG/150/30/5/-	197
20.2357	30	400H	STG	150	35	5	30/400H/STG/150/35/5/-	198
20.4826	30	400H	STG	150	45	5	30/400H/STG/150/45/5/-	200
20.6153	30	400H	STG	150	40	5	30/400H/STG/150/40/5/-	199
22.5810	30	400H	SS	50	30	5	30/400H/SS/50/30/5/-	147
23.2175	30	400H	SS	50	25	5	30/400H/SS/50/25/5/-	146
24.1689	30	400H	SS	50	40	5	30/400H/SS/50/40/5/-	149
24.3094	30	400H	SS	50	45	5	30/400H/SS/50/45/5/-	150
24.3617	30	400H	SS	50	35	5	30/400H/SS/50/35/5/-	148
24.6110	30	400H	OPP	100	25	5	30/400H/OPP/100/25/5/-	171

Table 21 VI<sub>15</sub> vs. System Descriptions

VI <sub>15</sub>	ROAD WIDTH (ft.)	LAMP/ LUMINAIRE	CONFIG- URATION	SPACING (ft.)	MOUNTING HEIGHT (ft.)	OVER- HANG (ft.)	SYSTEM CODE	CASE NO.
24.7177	30	400H	OPP	100	45	5	30/400H/OPP/100/45/5/-	175
24.7323	30	400H	STG	100	45	5	30/400H/STG/100/45/5/-	195
25.5116	30	400H	OPP	100	40	5	30/400H/OPP/100/40/5/-	174
25.5750	30	400H	OPP	100	30	5	30/400H/OPP/100/30/5/-	172
25.6962	30	400H	STG	100	40	5	30/400H/STG/100/40/5/-	194
25.8040	30	400H	OPP	100	35	5	30/400H/OPP/100/35/5/-	173
27.1775	30	400H	STG	100	35	5	30/400H/STG/100/35/5/-	193
27.6648	30	400H	STG	100	25	5	30/400H/STG/100/25/5/-	191
28.6726	30	400H	STG	100	30	5	30/400H/STG/100/30/5/-	192

Table 21 VI<sub>15</sub> vs. System Descriptions

VI <sub>15</sub>	ROAD WIDTH (ft.)	LAMP/ LUMINAIRE	CONFIG- URATION	SPACING (ft.)	MOUNTING HEIGHT (ft.)	OVER- HANG (ft.)	SYSTEM CODE	CASE NO.
2.2864	60	150H	OPP	250	25	11	60/150H/OPP/250/25/11/-	227
2.2942	60	150H	OPP	250	20	11	60/150H/OPP/250/20/11/-	226
2.6402	60	150H	OPP	200	20	11	60/150H/OPP/200/20/11/-	221
2.6828	60	150H	OPP	250	35	11	60/150H/OPP/250/35/11/-	229
2.8761	60	150H	STG	250	20	11	60/150H/STG/250/20/11/-	246
3.1613	60	150H	OPP	200	25	11	60/150H/OPP/200/25/11/-	222
3.2017	60	150H	STG	250	30	11	60/150H/OPP/250/30/11/-	228
3.6278	60	150H	OPP	250	40	11	60/150H/OPP/250/40/11/-	230
3.6798	60	150H	STG	250	25	11	60/150H/STG/250/25/11/-	247
3.9748	60	150H	STG	200	20	11	60/150H/STG/200/20/11/-	241
4.0945	60	150H	OPP	150	20	11	60/150H/OPP/150/20/11/-	216
4.2115	60	150H	OPP	200	30	11	60/150H/OPP/200/30/11/-	223
4.6917	60	150H	OPP	150	25	11	60/150H/OPP/150/25/11/-	217
4.8345	60	150H	STG	250	30	11	60/150H/STG/250/30/11/-	248

Table 21 VI<sub>15</sub> vs. System Descriptions

VI <sub>15</sub>	ROAD WIDTH (ft.)	LAMP/ LUMINAIRE	CONFIG- URATION	SPACING (ft.)	MOUNTING HEIGHT (ft.)	OVER- HANG (ft.)	SYSTEM CODE	CASE NO.
5.1449	60	150H	STG	150	20	11	60/150H/STG/150/20/11/-	236
5.3778	60	150H	STG	200	25	11	60/150H/STG/200/25/11/-	242
5.4357	60	150H	STG	250	35	11	60/150H/STG/250/35/11/-	249
6.2496	60	150H	OPP	200	35	11	60/150H/OPP/200/35/11/-	224
6.2879	60	150H	STG	200	30	11	60/150H/STG/200/30/11/-	243
6.8343	60	150H	STG	250	40	11	60/150H/STG/250/40/11/-	250
6.8785	60	150H	STG	200	35	11	60/150H/STG/200/35/11/-	244
7.0540	60	150H	STG	150	25	11	60/150H/STG/150/25/11/-	237
7.2044	60	150H	OPP	200	40	11	60/150H/OPP/200/40/11/-	225
8.0070	60	150H	OPP	150	30	11	60/150H/OPP/150/30/11/-	218
8.0145	60	150H	STG	200	40	11	60/150H/STG/200/40/11/-	245
8.7851	60	150H	STG	150	30	11	60/150H/STG/150/30/11/-	238
8.8724	60	150H	OPP	150	35	11	60/150H/OPP/150/35/11/-	219
9.2265	60	150H	STG	150	35	11	60/150H/STG/150/35/11/-	239

Table 21 VI<sub>15</sub> vs. System Descriptions

VI <sub>15</sub>	ROAD WIDTH (ft.)	LAMP/ LUMINAIRE	CONFIG- URATION	SPACING (ft.)	MOUNTING HEIGHT (ft.)	OVER- HANG (ft.)	SYSTEM CODE	CASE NO.
9.8073	60	150H	OPP	150	40	11	60/150H/OPP/150/40/11/-	220
10.1171	60	150H	OPP	100	20	11	60/150H/OPP/100/20/11/-	211
10.3387	60	150H	STG	150	40	11	60/150H/STG/150/40/11/-	240
10.5746	60	150H	STG	100	20	11	60/150H/STG/100/20/11/-	231
11.3604	60	150H	OPP	100	25	11	60/150H/OPP/100/25/11/-	212
11.8676	60	150H	STG	100	25	11	60/150H/STG/100/25/11/-	232
13.0628	60	150H	STG	100	30	11	60/150H/STG/100/30/11/-	233
13.2321	60	150H	STG	100	40	11	60/150H/STG/100/40/11/-	235
13.2493	60	150H	OPP	100	30	11	60/150H/OPP/100/30/11/-	213
13.5344	60	150H	OPP	100	35	11	60/150H/OPP/100/35/11/-	214
13.5397	60	150H	OPP	100	40	11	60/150H/OPP/100/40/11/-	215
13.7638	60	150H	STG	100	35	11	60/150H/STG/100/35/11/-	234

Table 21 VI<sub>15</sub> vs. System Descriptions

VI <sub>15</sub>	ROAD WIDTH (ft.)	LAMP/ LUMINAIRE	CONFIG- URATION	SPACING (ft.)	MOUNTING HEIGHT (ft.)	OVER- HANG (ft.)	SYSTEM CODE	CASE NO.
1.9193	30	150H	OPP	250	20	5	30/150H/OPP/250/20/5/-	291
1.9247	30	150H	STG	250	20	5	30/150H/STG/250/20/5/-	311
2.0357	30	150H	OPP	200	20	5	30/150H/OPP/200/20/5/-	286
2.1485	30	150H	SS	250	25	5	30/150H/SS/250/25/5/-	272
2.2219	30	150H	SS	200	20	5	30/150H/SS/200/20/5/-	266
2.4669	30	150H	SS	250	20	5	30/150H/SS/250/20/5/-	271
3.1809	30	150H	SS	200	25	5	30/150H/SS/200/25/5/-	267
3.6149	30	150H	SS	250	30	5	30/150H/SS/250/30/5/-	273
3.6173	30	150H	SS	150	25	5	30/150H/SS/150/25/5/-	262
3.6948	30	150H	OPP	250	25	5	30/150H/OPP/250/25/5/-	292
3.7245	30	150H	SS	250	35	5	30/150H/SS/250/35/5/-	274
4.1341	30	150H	SS	150	20	5	30/150H/SS/150/20/5/-	261
4.4224	30	150H	SS	250	40	5	30/150H/SS/250/40/5/-	275
4.7120	30	150H	OPP	150	20	5	30/150H/OPP/150/20/5/-	281

Table 21 VI<sub>15</sub> vs. System Descriptions

VI <sub>15</sub>	ROAD WIDTH (ft.)	LAMP/ LUMINAIRE	CONFIG- URATION	SPACING (ft.)	MOUNTING HEIGHT (ft.)	OVER- HANG (ft.)	SYSTEM CODE	CASE NO.
4.7637	30	150H	OPP	200	25	5	30 150H OPP 200 25 5/-	287
4.7845	30	150H	SS	200	30	5	30 150H SS 200 30 5/-	268
5.2618	30	150H	OPP	250	30	5	30 150H OPP 250 30 5/-	293
5.9171	30	150H	OPP	250	40	5	30 150H OPP 250 40 5/-	295
5.9532	30	150H	OPP	250	35	5	30 150H OPP 250 35 5/-	294
6.0134	30	150H	SS	200	35	5	30 150H SS 200 35 5/-	269
6.1738	30	150H	STG	250	25	5	30 150H STG 250 25 5/-	312
6.2823	30	150H	STG	150	20	5	30 150H STG 150 20 5/-	301
6.3489	30	150H	SS	100	20	5	30 150H SS 100 20 5/-	256
6.3874	30	150H	SS	150	35	5	30 150H SS 150 35 5/-	264
6.3895	30	150H	SS	200	40	5	30 150H SS 200 40 5/-	270
6.4648	30	150H	STG	200	20	5	30 150H STG 200 20 5/-	306
6.6181	30	150H	OPP	200	40	5	30 150H OPP 200 40 5/-	290
6.7663	30	150H	OPP	200	30	5	30 150H OPP 200 30 5/-	288

Table 21 VI<sub>15</sub> vs. System Descriptions

VI <sub>15</sub>	ROAD WIDTH (ft.)	LAMP/ LUMINAIRE	CONFIG- URATION	SPACING (ft.)	MOUNTING HEIGHT (ft.)	OVER- HANG (ft.)	SYSTEM CODE	CASE NO.
7.2209	30	150H	STG	250	30	5	30/150H/STG/250/30/5/-	313
7.3357	30	150H	SS	150	30	5	30/150H/SS/150/30/5/-	263
7.7297	30	150H	SS	150	40	5	30/150H/SS/150/40/5/-	265
8.0418	30	150H	STG	200	25	5	30/150H/STG/200/25/5/-	307
8.2579	30	150H	OPP	200	35	5	30/150H/OPP/200/35/5/-	289
8.3698	30	150H	STG	250	35	5	30/150H/STG/250/35/5/-	314
8.5740	30	150H	SS	100	25	5	30/150H/SS/100/25/5/-	257
8.7939	30	150H	OPP	150	25	5	30/150H/OPP/150/25/5/-	282
9.1488	30	150H	SS	50	20	5	30/150H/SS/50/20/5/-	251
9.3151	30	150H	STG	250	40	5	30/150H/STG/250/40/5/-	315
10.1533	30	150H	STG	150	25	5	30/150H/STG/150/25/5/-	302
10.4438	30	150H	OPP	150	30	5	30/150H/OPP/150/30/5/-	283
10.5831	30	150H	SS	100	40	5	30/150H/SS/100/40/5/-	260
10.6836	30	150H	SS	100	30	5	30/150H/SS/100/30/5/-	258

Table 21 VI<sub>15</sub> vs. System Descriptions

VI <sub>15</sub>	ROAD WIDTH (ft.)	LAMP/ LUMINAIRE	CONFIG- URATION	SPACING (ft.)	MOUNTING HEIGHT (ft.)	OVER- HANG (ft.)	SYSTEM CODE	CASE NO.
11.0183	30	150H	SS	100	35	5	30 150H SS 100 35 5/-	259
11.1714	30	150H	STG	200	35	5	30 150H STG 200 35 5/-	309
11.2463	30	150H	STG	150	35	5	30 150H STG 150 35 5/-	304
11.3684	30	150H	SS	50	25	5	30 150H SS 50 25 5/-	252
11.4285	30	150H	STG	200	40	5	30 150H STG 200 40 5/-	310
11.9088	30	150H	OPP	150	35	5	30 150H OPP 150 35 5/-	284
11.9233	30	150H	STG	200	30	5	30 150H STG 200 30 5/-	308
12.2511	30	150H	STG	150	40	5	30 150H STG 150 40 5/-	305
12.8284	30	150H	STG	150	30	5	30 150H STG 150 30 5/-	303
13.0531	30	150H	SS	50	30	5	30 150H SS 50 30 5/-	253
13.1808	30	150H	OPP	150	40	5	30 150H OPP 150 40 5/-	285
13.2131	30	150H	SS	50	35	5	30 150H SS 50 35 5/-	254
13.5867	30	150H	STG	100	20	5	30 150H STG 100 20 5/-	296
13.6169	30	150H	SS	50	40	5	30 150H SS 50 40 5/-	255

Table 21 VI<sub>15</sub> vs. System Descriptions

VI <sub>15</sub>	ROAD WIDTH (ft.)	LAMP/ LUMINAIRE	CONFIG- URATION	SPACING (ft.)	MOUNTING HEIGHT (ft.)	OVER- HANG (ft.)	SYSTEM CODE	CASE NO.
13.6893	30	150H	OPP	100	20	5	30 150H OPP 100 20 5 -	276
14.7006	30	150H	OPP	100	25	5	30 150H OPP 100 25 5 -	277
14.9984	30	150H	STG	100	40	5	30 150H STG 100 40 5 -	300
15.5528	30	150H	OPP	100	40	5	30 150H OPP 100 40 5 -	280
15.9734	30	150H	OPP	100	30	5	30 150H OPP 100 30 5 -	278
16.1547	30	150H	STG	100	35	5	30 150H STG 100 35 5 -	299
16.3320	30	150H	OPP	100	35	5	30 150H OPP 100 35 5 -	279
16.3631	30	150H	STG	100	30	5	30 150H STG 100 30 5 -	298
16.3738	30	150H	STG	100	25	5	30 150H STG 100 25 5 -	297

Table 21 VI<sub>15</sub> vs. System Descriptions

VI <sub>15</sub>	ROAD WIDTH (ft.)	LAMP/ LUMINAIRE	CONFIG- URATION	SPACING (ft.)	MOUNTING HEIGHT (ft.)	OVER- HANG (ft.)	SYSTEM CODE	CASE NO.
.9382	60	175 M	OPP	250	25	11	60/175M/OPP/250/25/11/-	332
1.0687	60	175 M	STG	250	20	11	60/175M/STG/250/20/11/-	351
1.2773	60	175 M	STG	250	25	11	60/175M/STG/250/25/11/-	352
1.3971	60	175 M	OPP	250	35	11	60/175M/OPP/250/35/11/-	334
1.5141	60	175 M	OPP	250	30	11	60/175M/OPP/250/30/11/-	333
1.5488	60	175 M	OPP	250	20	11	60/175M/OPP/250/20/11/-	331
1.5886	60	175 M	OPP	250	40	11	60/175M/OPP/250/40/11/-	335
1.6928	60	175 M	OPP	200	25	11	60/175M/OPP/200/25/11/-	327
1.7212	60	175 M	STG	250	30	11	60/175M/STG/250/30/11/-	353
1.7247	60	175 M	OPP	200	20	11	60/175M/OPP/200/20/11/-	326
1.9305	60	175 M	STG	200	20	11	60/175M/STG/200/20/11/-	346
1.9475	60	175 M	STG	250	40	11	60/175M/STG/250/40/11/-	355
2.0714	60	175 M	OPP	200	40	11	60/175M/OPP/200/40/11/-	330
2.1230	60	175 M	STG	250	35	11	60/175M/STG/250/35/11/-	354

Table 21 VI<sub>15</sub> vs. System Descriptions

VI <sub>15</sub>	ROAD WIDTH (ft.)	LAMP/ LUMINAIRE	CONFIG- URATION	SPACING (ft.)	MOUNTING HEIGHT (ft.)	OVER- HANG (ft.)	SYSTEM CODE	CASE NO.
2.2129	60	175M	OPP	200	30	11	60/175M/OPP/200/30/11/-	328
2.2254	60	175M	OPP	150	20	11	60/175M/OPP/150/20/11/-	321
2.2541	60	175M	STG	200	30	11	60/175M/STG/200/30/11/-	348
2.2884	60	175M	STG	200	25	11	60/175M/STG/200/25/11/-	347
2.3312	60	175M	OPP	200	35	11	60/175M/OPP/200/35/11/-	329
2.6655	60	175M	STG	200	35	11	60/175M/STG/200/35/11/-	349
2.9601	60	175M	STG	200	40	11	60/175M/STG/200/40/11/-	350
3.0541	60	175M	STG	150	20	11	60/175M/STG/150/20/11/-	341
3.0709	60	175M	OPP	150	30	11	60/175M/OPP/150/30/11/-	323
3.1235	60	175M	OPP	150	35	11	60/175M/OPP/150/35/11/-	324
3.2595	60	175M	OPP	150	25	11	60/175M/OPP/150/25/11/-	322
3.6687	60	175M	STG	150	30	11	60/175M/STG/150/30/11/-	343
3.6716	60	175M	STG	150	35	11	60/175M/STG/150/35/11/-	344
3.9155	60	175M	OPP	150	40	11	60/175M/OPP/150/40/11/-	325

Table 21 VI<sub>15</sub> vs. System Descriptions

VI <sub>15</sub>	ROAD WIDTH (ft.)	LAMP/ LUMINAIRE	CONFIG- URATION	SPACING (ft.)	MOUNTING HEIGHT (ft.)	OVER- HANG (ft.)	SYSTEM CODE	CASE NO.
4.1958	60	175M	STG	150	25	11	60/175M/STG/150/25/11/-	342
4.4269	60	175M	OPP	100	25	11	60/175M/OPP/100/25/11/-	317
5.0900	60	175M	STG	150	40	11	60/175M/STG/150/40/11/-	345
5.4694	60	175M	OPP	100	20	11	60/175M/OPP/100/20/11/-	316
5.9919	60	175M	STG	100	20	11	60/175M/STG/100/20/11/-	336
6.7559	60	175M	OPP	100	30	11	60/175M/OPP/100/30/11/-	318
6.8337	60	175M	OPP	100	35	11	60/175M/OPP/100/35/11/-	319
7.1427	60	175M	OPP	100	40	11	60/175M/OPP/100/40/11/-	320
7.1648	60	175M	STG	100	40	11	60/175M/STG/100/40/11/-	340
7.4184	60	175M	STG	100	30	11	60/175M/STG/100/30/11/-	338
7.6388	60	175M	STG	100	25	11	60/175M/STG/100/25/11/-	337
8.0377	60	175M	STG	100	35	11	60/175M/STG/100/35/11/-	339

Table 21 VI<sub>15</sub> vs. System Descriptions

VI <sub>15</sub>	ROAD WIDTH (ft.)	LAMP/ LUMINAIRE	CONFIG- URATION	SPACING (ft.)	MOUNTING HEIGHT (ft.)	OVER- HANG (ft.)	SYSTEM CODE	CASE NO.
.9866	30	175M	SS	250	25	5	30/175M/SS/250/25/5/-	377
1.2230	30	175M	SS	250	30	5	30/175M/SS/250/30/5/-	378
1.2358	30	175M	SS	250	20	5	30/175M/SS/250/20/5/-	376
1.2875	30	175M	SS	200	25	5	30/175M/SS/200/25/5/-	372
1.3122	30	175M	SS	150	20	5	30/175M/SS/150/20/5/-	366
1.3859	30	175M	SS	250	40	5	30/175M/SS/250/40/5/-	380
1.5303	30	175M	STG	250	20	5	30/175M/STG/250/20/5/-	416
1.5325	30	175M	SS	200	20	5	30/175M/SS/200/20/5/-	371
1.5578	30	175M	OPP	200	20	5	30/175M/OPP/200/20/5/-	391
1.6119	30	175M	OPP	250	25	5	30/175M/OPP/250/25/5/-	397
1.7910	30	175M	OPP	250	20	5	30/175M/OPP/250/20/5/-	396
1.8335	30	175M	SS	150	25	5	30/175M/SS/150/25/5/-	367
1.8994	30	175M	SS	250	40	5	30/175M/SS/250/40/5/-	379
1.9295	30	175M	SS	200	30	5	30/175M/SS/200/30/5/-	373

Table 21 VI<sub>15</sub> vs. System Descriptions

VI <sub>15</sub>	ROAD WIDTH (ft.)	LAMP/ LUMINAIRE	CONFIG- URATION	SPACING (ft.)	MOUNTING HEIGHT (ft.)	OVER- HANG (ft.)	SYSTEM CODE	CASE NO.
2.0843	30	175M	SS	200	35	5	30 175M SS 200 35 5/-	374
2.3786	30	175M	OPP	200	25	5	30 175M OPP 200 25 5/-	392
2.4275	30	175M	SS	200	40	5	30 175M SS 200 40 5/-	375
2.4892	30	175M	OPP	250	40	5	30 175M OPP 250 40 5/-	400
2.6055	30	175M	STG	150	20	5	30 175M STG 150 20 5/-	406
2.6889	30	175M	OPP	250	30	5	30 175M OPP 250 30 5/-	398
2.8522	30	175M	OPP	150	20	5	30 175M OPP 150 20 5/-	386
2.9347	30	175M	STG	200	20	5	30 175M STG 200 20 5/-	411
3.0469	30	175M	STG	250	25	5	30 175M STG 250 25 5/-	417
3.3763	30	175M	OPP	250	35	5	30 175M OPP 250 35 5/-	399
3.5293	30	175M	SS	150	30	5	30 175M SS 150 30 5/-	368
3.6234	30	175M	OPP	200	40	5	30 175M OPP 200 40 5/-	395
3.6273	30	175M	OPP	200	30	5	30 175M OPP 200 30 5/-	393
3.6277	30	175M	OPP	150	25	5	30 175M OPP 150 25 5/-	387

Table 21 VI<sub>15</sub> vs. System Descriptions

VI <sub>15</sub>	ROAD WIDTH (ft.)	LAMP/ LUMINAIRE	CONFIG- URATION	SPACING (ft.)	MOUNTING HEIGHT (ft.)	OVER- HANG (ft.)	SYSTEM CODE	CASE NO.
3.6333	30	175 M	STG	250	30	5	30/175M/STG/250/30/5/-	418
3.6571	30	175 M	OPP	200	35	5	30/175M/OPP/200/35/5/-	394
3.7166	30	175 M	SS	100	20	5	30/175M/SS/100/20/5/-	361
3.7608	30	175 M	SS	150	35	5	30/175M/SS/150/35/5/-	369
3.8904	30	175 M	STG	250	35	5	30/175M/STG/250/35/5/-	419
3.9513	30	175 M	STG	250	40	5	30/175M/STG/250/40/5/-	420
4.2315	30	175 M	OPP	100	20	5	30/175M/OPP/100/20/5/-	381
4.4880	30	175 M	SS	150	40	5	30/175M/SS/150/40/5/-	370
4.6807	30	175 M	SS	100	25	5	30/175M/SS/100/25/5/-	362
4.7970	30	175 M	STG	200	25	5	30/175M/STG/200/25/5/-	412
4.8179	30	175 M	STG	100	20	5	30/175M/STG/100/20/5/-	401
5.1241	30	175 M	OPP	150	30	5	30/175M/OPP/150/30/5/-	388
5.1328	30	175 M	STG	150	25	5	30/175M/STG/150/25/5/-	407
5.1990	30	175 M	STG	200	30	5	30/175M/STG/200/30/5/-	413

Table 21 VI<sub>15</sub> vs. System Descriptions

VI <sub>15</sub>	ROAD WIDTH (ft.)	LAMP/ LUMINAIRE	CONFIG- URATION	SPACING (ft.)	MOUNTING HEIGHT (ft.)	OVER- HANG (ft.)	SYSTEM CODE	CASE NO.
5.2864	30	175 M	STG	200	35	5	30/175M   STG/200/35/5/-	414
5.7404	30	175 M	STG	200	40	5	30/175M   STG/200/40/5/-	415
6.4474	30	175 M	SS	100	30	5	30/175M   SS/100/30/5/-	363
6.7102	30	175 M	OPP	150	35	5	30/175M   OPP/150/35/5/-	389
6.7599	30	175 M	STG	150	30	5	30/175M   STG/150/30/5/-	408
6.8384	30	175 M	SS	50	20	5	30/175M   SS/50/20/5/-	356
7.0530	30	175 M	SS	100	35	5	30/175M   SS/100/35/5/-	364
7.0533	30	175 M	SS	100	40	5	30/175M   SS/100/40/5/-	365
7.0961	30	175 M	OPP	100	25	5	30/175M   OPP/100/25/5/-	382
7.1951	30	175 M	OPP	150	40	5	30/175M   OPP/150/40/5/-	390
7.4569	30	175 M	STG	100	25	5	30/175M   STG/100/25/5/-	402
7.5989	30	175 M	STG	150	35	5	30/175M   STG/150/35/5/-	409
8.0835	30	175 M	STG	150	40	5	30/175M   STG/150/40/5/-	410
8.1781	30	175 M	OPP	100	30	5	30/175M   OPP/100/30/5/-	383

Table 21 VI<sub>15</sub> vs. System Descriptions

VI <sub>15</sub>	ROAD WIDTH (ft.)	LAMP/ LUMINAIRE	CONFIG- URATION	SPACING (ft.)	MOUNTING HEIGHT (ft.)	OVER- HANG (ft.)	SYSTEM CODE	CASE NO.
8.6307	30	175M	SS	50	25	5	30 175M SS 50 25 5/-	357
8.7613	30	175M	OPP	100	35	5	30 175M OPP 100 35 5/-	384
8.8902	30	175M	STG	100	30	5	30 175M STG 100 30 5/-	403
9.6593	30	175M	STG	100	35	5	30 175M STG 100 35 5/-	404
9.8373	30	175M	OPP	100	40	5	30 175M OPP 100 40 5/-	385
10.0726	30	175M	STG	100	40	5	30 175M STG 100 40 5/-	405
10.1143	30	175M	SS	50	30	5	30 175M SS 50 30 5/-	358
10.4221	30	175M	SS	50	40	5	30 175M SS 50 40 5/-	360
10.7322	30	175M	SS	50	35	5	30 175M SS 50 35 5/-	359

Table 22. Costs of New Systems

SYSTEM CODE	CASE NO.	VI <sub>15</sub>	ENERGY USE (kwh/mi/yr)	INITIAL COST		ANNUAL COST		TOTAL COSTS (\$/mi/yr)
				TOTAL (\$/mi)	ANNUAL (\$/mi/yr)	ENERGY (\$/mi/yr)	MAINTEN- ANCE (\$/mi/yr)	
60/400M/OPP/100/25/11/M	1	7.7	1704	98040	10563	15228	752	26543
60/400M/OPP/100/30/11/M	2	9.4	1704	98040	10563	15228	752	26543
60/400M/OPP/100/35/11/M	3	10.9	1704	98040	10563	15228	752	26543
60/400M/OPP/100/40/11/M	4	11.8	1704	120960	13084	15228	752	29043
60/400M/OPP/100/45/11/M	5	12.7	1704	120960	13084	15228	752	29043
60/400M/OPP/150/25/11/M	6	2.6	1147	69205	7456	10749	530	18735
60/400M/OPP/150/30/11/M	7	5.2	1147	69205	7456	10749	530	18735
60/400M/OPP/150/35/11/M	8	7.2	1147	69205	7456	10749	530	18735
60/400M/OPP/150/40/11/M	9	8.0	1147	85383	9235	10749	530	20514
60/400M/OPP/150/45/11/M	10	8.3	1147	85383	9235	10749	530	20514
60/400M/OPP/200/25/11/M	11	1.5	852	51904	5592	8062	398	14052
60/400M/OPP/200/30/11/M	12	2.0	852	51904	5592	8062	398	14052
60/400M/OPP/200/35/11/M	13	3.3	852	51904	5592	8062	398	14052
60/400M/OPP/200/40/11/M	14	4.4	852	64038	6927	8062	398	15387
60/400M/OPP/200/45/11/M	15	5.3	852	64038	6927	8062	398	15387
60/400M/OPP/250/25/11/M	16	0.9	688	44214	4764	6867	339	11970

Table 22 Costs of New Systems

SYSTEM CODE	CASE NO.	VI <sub>15</sub>	ENERGY USE (kwh/mi/yr) x10 <sup>2</sup>	INITIAL COST		ANNUAL COST		TOTAL COSTS (\$/mi/yr)
				TOTAL (\$/mi)	ANNUAL (\$/mi/yr)	ENERGY (\$/mi/yr)	MAINTEN- ANCE (\$/mi/yr)	
60/400M/OPP/250/30/11/M	17	2.1	688	44214	4764	6867	339	11970
60/400M/OPP/250/35/11/M	18	1.7	688	44214	4764	6867	339	11970
60/400M/OPP/250/40/11/M	19	2.6	688	54550	5900	6867	339	13106
60/400M/OPP/250/45/11/M	20	3.4	688	54550	5900	6867	339	13106
60/400M/STG/100/25/11/M	21	10.5	1704	98040	10563	15228	752	26543
60/400M/STG/100/30/11/M	22	12.4	1704	98040	10563	15228	752	26543
60/400M/STG/100/35/11/M	23	13.4	1704	98040	10563	15228	752	26543
60/400M/STG/100/40/11/M	24	13.8	1704	120960	13084	15228	752	29043
60/400M/STG/100/45/11/M	25	13.8	1704	120960	13084	15228	752	29043
60/400M/STG/150/25/11/M	26	5.5	1147	69205	7456	10749	530	18735
60/400M/STG/150/30/11/M	27	7.3	1147	69205	7456	10749	530	18735
60/400M/STG/150/35/11/M	28	9.0	1147	69205	7456	10749	530	18735
60/400M/STG/150/40/11/M	29	9.9	1147	85383	9235	10749	530	20514
60/400M/STG/150/45/11/M	30	10.7	1147	85383	9235	10749	530	20514
60/400M/STG/200/25/11/M	31	3.7	852	51904	5592	8062	398	14052
60/400M/STG/200/30/11/M	32	4.6	852	51904	5592	8062	398	14052

Table 22 Costs of New Systems

[illegible]

Table 22 Costs of New Systems

SYSTEM CODE	CASE NO.	VI <sub>15</sub>	ENERGY USE (kwh/mi/yr) x10 <sup>2</sup>	INITIAL COST		ANNUAL COST		TOTAL COSTS (\$/mi/yr)
				TOTAL (\$/mi)	ANNUAL (\$/mi/yr)	ENERGY (\$/mi/yr)	MAINTEN- ANCE (\$/mi/yr)	
30/400M/SS/50/25/5/M	41	11.1	1720	96118	10356	14929	737	26022
30/400M/SS/50/30/5/M	42	12.2	1720	96118	10356	14929	737	26022
30/400M/SS/50/35/5/M	43	13.1	1720	96118	10356	14929	737	26022
30/400M/SS/50/40/5/M	44	13.9	1720	118588	12827	14929	737	28493
30/400M/SS/50/45/5/M	45	14.1	1720	118588	12827	14929	737	28493
30/400M/SS/100/25/5/M	46	5.6	852	49020	5281	7614	376	13271
30/400M/SS/100/30/5/M	47	7.4	852	49020	5281	7614	376	13271
30/400M/SS/100/35/5/M	48	9.1	852	49020	5281	7614	376	13271
30/400M/SS/100/40/5/M	49	9.6	852	60480	6542	7614	376	14532
30/400M/SS/100/45/5/M	50	9.8	852	60480	6542	7614	376	14532
30/400M/SS/150/25/5/M	51	3.0	573	34602	3728	5374	265	9367
30/400M/SS/150/30/5/M	52	4.3	573	34602	3728	5374	265	9367
30/400M/SS/150/35/5/M	53	5.7	573	34602	3728	5374	265	9367
30/400M/SS/150/40/5/M	54	6.5	573	42692	4618	5374	265	10257
30/400M/SS/150/45/5/M	55	7.3	573	42692	4618	5374	265	10257
30/400M/SS/200/25/5/M	56	1.2	426	25952	2796	4031	199	7026

Table 22 Costs of New Systems

SYSTEM CODE	CASE NO.	VI <sub>15</sub>	ENERGY USE (kwh/mj/yr) x10 <sup>2</sup>	INITIAL COST		ANNUAL COST		TOTAL COSTS (\$/mi/yr)
				TOTAL (\$/mi)	ANNUAL (\$/mi/yr)	ENERGY (\$/mi/yr)	MAINTEN- ANCE (\$/mi/yr)	
30/400M/ss/200/30/5/M	57	2.0	426	25952	2796	4031	199	7026
30/400M/ss/200/35/5/M	58	3.5	426	25952	2796	4031	199	7026
30/400M/ss/200/40/5/M	59	4.4	426	32019	3463	4031	199	7693
30/400M/ss/200/45/5/M	60	5.3	426	32019	3463	4031	199	7693
30/400M/ss/250/25/5/M	61	0.9	344	22107	2382	3434	170	5986
30/400M/ss/250/30/5/M	62	1.2	344	22107	2382	3434	170	5986
30/400M/ss/250/35/5/M	63	1.5	344	22107	2382	3434	170	5986
30/400M/ss/250/40/5/M	64	3.0	344	27275	2950	3434	170	6554
30/400M/ss/250/45/5/M	65	3.9	344	27275	2950	3434	170	6554
30/400M/oppp/100/25/5/M	66	10.9	1704	98040	10563	15228	752	26543
30/400M/oppp/100/30/5/M	67	12.8	1704	98040	10563	15228	752	26543
30/400M/oppp/100/35/5/M	68	14.0	1704	98040	10563	15228	752	26543
30/400M/oppp/100/40/5/M	69	14.7	1704	120960	13084	15228	752	29043
30/400M/oppp/100/45/5/M	70	15.4	1704	120960	13084	15228	752	29043
30/400M/oppp/150/25/5/M	71	4.1	1147	69205	7456	10749	530	18735
30/400M/oppp/150/30/5/M	72	7.0	1147	69205	7456	10749	530	18735

Table 22 Costs of New Systems

SYSTEM CODE	CASE NO.	VI <sub>15</sub>	ENERGY USE (kwh/mi <sup>2</sup> /yr) x10 <sup>2</sup>	INITIAL COST		ANNUAL COST		TOTAL COSTS (\$/mi/yr)
				TOTAL (\$/mi)	ANNUAL (\$/mi/yr)	ENERGY (\$/mi/yr)	MAINTEN- ANCE (\$/mi/yr)	
30/400M/OPP/150/35/5/M	73	8.8	1147	69205	7456	10749	530	18735
30/400M/OPP/150/40/5/M	74	10.0	1147	85383	9235	10749	530	20514
30/400M/OPP/150/45/5/M	75	10.8	1147	85383	9235	10749	530	20514
30/400M/OPP/200/25/5/M	76	1.6	852	51904	5592	8062	398	14052
30/400M/OPP/200/30/5/M	77	3.1	852	51904	5592	8062	398	14052
30/400M/OPP/200/35/5/M	78	5.1	852	51904	5592	8062	398	14052
30/400M/OPP/200/40/5/M	79	6.8	852	64038	6927	8062	398	15387
30/400M/OPP/200/45/5/M	80	7.4	852	64038	6927	8062	398	15387
30/400M/OPP/250/25/5/M	81	1.1	688	44214	4764	6867	339	11970
30/400M/OPP/250/30/5/M	82	1.7	688	44214	4764	6867	339	11970
30/400M/OPP/250/35/5/M	83	2.6	688	44214	4764	6867	339	11970
30/400M/OPP/250/40/5/M	84	4.1	688	54550	5900	6867	339	13106
30/400M/OPP/250/45/5/M	85	5.2	688	54550	5900	6867	339	13106
30/400M/STG/100/25/5/M	86	15.2	1704	98040	10563	15228	752	26543
30/400M/STG/100/30/5/M	87	16.3	1704	98040	10563	15228	752	26543
30/400M/STG/100/35/5/M	88	16.3	1704	98040	10563	15228	752	26543

Table 22 Costs of New Systems

SYSTEM CODE	CASE NO.	VI <sub>15</sub>	ENERGY USE (kwh/mi/yr) x10 <sup>2</sup>	INITIAL COST		ANNUAL COST		TOTAL COSTS (\$/mi/yr)
				TOTAL (\$/mi)	ANNUAL (\$/mi/yr)	ENERGY (\$/mi/yr)	MAINTEN- ANCE (\$/mi/yr)	
30/400M/STG/100/40/5/M	89	16.3	1704	120960	13084	15228	752	29043
30/400M/STG/100/45/5/M	90	16.2	1704	120960	13084	15228	752	29043
30/400M/STG/150/25/5/M	91	8.8	1147	69205	7456	10749	530	18735
30/400M/STG/150/30/5/M	92	11.0	1147	69205	7456	10749	530	18735
30/400M/STG/150/35/5/M	93	12.3	1147	69205	7456	10749	530	18735
30/400M/STG/150/40/5/M	94	13.0	1147	85383	9235	10749	530	20514
30/400M/STG/150/45/5/M	95	13.2	1147	85383	9235	10749	530	20514
30/400M/STG/200/25/5/M	96	4.9	852	51904	5592	8062	398	14052
30/400M/STG/200/30/5/M	97	6.9	852	51904	5592	8062	398	14052
30/400M/STG/200/35/5/M	98	9.0	852	51904	5592	8062	398	14052
30/400M/STG/200/40/5/M	99	10.1	852	64038	6927	8062	398	15387
30/400M/STG/200/45/5/M	100	10.7	852	64038	6927	8062	398	15387
30/400M/STG/250/25/5/M	101	3.1	688	44214	4764	6867	339	11970
30/400M/STG/250/30/5/M	102	5.1	688	44214	4764	6867	339	11970
30/400M/STG/250/35/5/M	103	6.2	688	44214	4764	6867	339	11970
30/400M/STG/250/40/5/M	104	7.2	688	54550	5900	6867	339	13106
30/400M/STG/250/45/5/M	105	8.3	688	54550	5900	6867	339	13106

Table 22 Costs of New Systems

SYSTEM CODE	CASE NO.	VI <sub>15</sub>	ENERGY USE (kwh/mi/yr) x10 <sup>2</sup>	INITIAL COST		ANNUAL COST		TOTAL COSTS (\$/mi/yr)
				TOTAL (\$/mi)	ANNUAL (\$/mi/yr)	ENERGY (\$/mi/yr)	MAINTEN- ANCE (\$/mi/yr)	
60/400H/OPP/100/25/11/M	106	16.0	1704	104589	11283	15228	2548	29059
60/400H/OPP/100/30/11/M	107	17.7	1704	104589	11283	15228	2548	29059
60/400H/OPP/100/35/11/M	108	17.7	1704	104589	11283	15228	2548	29059
60/400H/OPP/100/40/11/M	109	18.0	1704	127508	13804	15228	2548	31580
60/400H/OPP/100/45/11/M	110	18.0	1704	127508	13804	15228	2548	31580
60/400H/OPP/150/25/11/M	111	6.1	1147	73827	7964	10749	1799	20511
60/400H/OPP/150/30/11/M	112	10.0	1147	73827	7964	10749	1799	20511
60/400H/OPP/150/35/11/M	113	12.6	1147	73827	7964	10749	1799	20511
60/400H/OPP/150/40/11/M	114	13.9	1147	90005	9744	10749	1799	22292
60/400H/OPP/150/45/11/M	115	14.7	1147	90005	9744	10749	1799	22292
60/400H/OPP/200/25/11/M	116	2.1	852	55371	5973	8062	1349	15384
60/400H/OPP/200/30/11/M	117	3.0	852	55371	5973	8062	1349	15384
60/400H/OPP/200/35/11/M	118	5.8	852	55371	5973	8062	1349	15384
60/400H/OPP/200/40/11/M	119	8.5	852	67504	7308	8062	1349	16719
60/400H/OPP/200/45/11/M	120	10.4	852	67504	7308	8062	1349	16719
60/400H/OPP/250/25/11/M	121	1.3	688	47167	5089	6867	1149	13105

Table 22 Costs of New Systems

SYSTEM CODE	CASE NO.	VI <sub>15</sub>	ENERGY USE (kwh/mi/yr) x10 <sup>2</sup>	INITIAL COST		ANNUAL COST		TOTAL COSTS (\$/mi/yr)
				TOTAL (\$/mi)	ANNUAL (\$/mi/yr)	ENERGY (\$/mi/yr)	MAINTEN- ANCE (\$/mi/yr)	
60/400H/OPP/250/30/11/M	122	3.0	688	47167	5089	6867	1149	13105
60/400H/OPP/250/35/11/M	123	2.1	688	47167	5089	6867	1149	13105
60/400H/OPP/250/40/11/M	124	3.7	688	57504	6225	6867	1149	14241
60/400H/OPP/250/45/11/M	125	5.1	688	57504	6225	6867	1149	14241
60/400H/STG/100/25/11/M	126	16.5	1704	104589	11283	15228	2548	29059
60/400H/STG/100/30/11/M	127	19.1	1704	104589	11283	15228	2548	29059
60/400H/STG/100/35/11/M	128	18.7	1704	104589	11283	15228	2548	29059
60/400H/STG/100/40/11/M	129	18.2	1704	127508	13804	15228	2548	31580
60/400H/STG/100/45/11/M	130	18.5	1704	127508	13804	15228	2548	31580
60/400H/STG/150/25/11/M	131	10.0	1147	73827	7964	10749	1799	20511
60/400H/STG/150/30/11/M	132	13.1	1147	73827	7964	10749	1799	20511
60/400H/STG/150/35/11/M	133	14.2	1147	73827	7964	10749	1799	20511
60/400H/STG/150/40/11/M	134	15.0	1147	90005	9744	10749	1799	22292
60/400H/STG/150/45/11/M	135	15.5	1147	90005	9744	10749	1799	22292
60/400H/STG/200/25/11/M	136	4.5	852	55371	5973	8062	1349	15384
60/400H/STG/200/30/11/M	137	8.2	852	55371	5973	8062	1349	15384

Table 22 Costs of New Systems

[illegible]

Table 22 Costs of New Systems

SYSTEM CODE	CASE NO.	VI <sub>15</sub>	ENERGY USE (kwh/mi/yr) x10 <sup>6</sup>	INITIAL COST		ANNUAL COST		TOTAL COSTS (\$/mi/yr)
				TOTAL (\$/mi)	ANNUAL (\$/mi/yr)	ENERGY (\$/mi/yr)	MAINTEN- ANCE (\$/mi/yr)	
30/400H/SS/50/25/5/M	146	23.2	1720	102538	11062	14929	2498	28489
30/400H/SS/50/30/5/M	147	22.6	1720	102538	11062	14929	2498	28489
30/400H/SS/50/35/5/M	148	24.4	1720	102538	11062	14929	2498	28489
30/400H/SS/50/40/5/M	149	24.2	1720	125008	13533	14929	2498	30960
30/400H/SS/50/45/5/M	150	24.3	1720	125008	13533	14929	2498	30960
30/400H/SS/100/25/5/M	151	13.0	852	52294	5642	7614	1274	14530
30/400H/SS/100/30/5/M	152	15.0	852	52294	5642	7614	1274	14530
30/400H/SS/100/35/5/M	153	16.6	852	52294	5642	7614	1274	14530
30/400H/SS/100/40/5/M	154	16.9	852	63754	6902	7614	1274	15790
30/400H/SS/100/45/5/M	155	17.1	852	63754	6902	7614	1274	15790
30/400H/SS/150/25/5/M	156	6.1	573	36914	3982	5374	899	10255
30/400H/SS/150/30/5/M	157	9.8	573	36914	3982	5374	899	10255
30/400H/SS/150/35/5/M	158	11.5	573	36914	3982	5374	899	10255
30/400H/SS/150/40/5/M	159	12.9	573	45003	4872	5374	899	11145
30/400H/SS/150/45/5/M	160	13.5	573	45003	4872	5374	899	11145
30/400H/SS/200/25/5/M	161	1.9	426	27685	2987	4031	674	7692

Table 22 Costs of New Systems

SYSTEM CODE	CASE NO.	VI <sub>15</sub>	ENERGY USE (kwh/mi/yr) x10 <sup>6</sup>	INITIAL COST		ANNUAL COST		TOTAL COSTS (\$/mi/yr)
				TOTAL (\$/mi)	ANNUAL (\$/mi/yr)	ENERGY (\$/mi/yr)	MAINTEN- ANCE (\$/mi/yr)	
30/400H/SS/200/30/5/M	162	4.3	426	27685	2987	4031	674	7692
30/400H/SS/200/35/5/M	163	6.2	426	27685	2987	4031	674	7692
30/400H/SS/200/40/5/M	164	8.1	426	33752	3654	4031	674	8359
30/400H/SS/200/45/5/M	165	9.5	426	33752	3654	4031	674	8359
30/400H/SS/250/25/5/M	166	1.5	344	23584	2544	3434	575	6552
30/400H/SS/250/30/5/M	167	2.4	344	23584	2544	3434	575	6552
30/400H/SS/250/35/5/M	168	3.0	344	23584	2544	3434	575	6552
30/400H/SS/250/40/5/M	169	3.8	344	28752	3113	3434	575	7122
30/400H/SS/250/45/5/M	170	5.8	344	28752	3113	3434	575	7122
30/400H/OPP/100/25/5/M	171	24.6	1704	104589	11283	15228	2548	29059
30/400H/OPP/100/30/5/M	172	25.6	1704	104589	11283	15228	2548	29059
30/400H/OPP/100/35/5/M	173	25.8	1704	104589	11283	15228	2548	29059
30/400H/OPP/100/40/5/M	174	25.5	1704	127508	13804	15228	2548	31580
30/400H/OPP/100/45/5/M	175	24.7	1704	127508	13804	15228	2548	31580
30/400H/OPP/150/25/5/M	176	7.2	1147	73827	7964	10749	1799	20511
30/400H/OPP/150/30/5/M	177	12.8	1147	73827	7964	10749	1799	20511

Table 22 Costs of New Systems

SYSTEM CODE	CASE NO.	VI <sub>15</sub>	ENERGY USE (kwh/mi/yr) x10 <sup>6</sup>	INITIAL COST		ANNUAL COST		TOTAL COSTS (\$/mi/yr)
				TOTAL (\$/mi)	ANNUAL (\$/mi/yr)	ENERGY (\$/mi/yr)	MAINTEN- ANCE (\$/mi/yr)	
30/400H/OPP/150/35/5/M	178	15.9	1147	73827	7964	10749	1799	20511
30/400H/OPP/150/40/5/M	179	17.5	1147	90005	9744	10749	1799	22292
30/400H/OPP/150/45/5/M	180	17.9	1147	90005	9744	10749	1799	22292
30/400H/OPP/200/25/5/M	181	5.4	852	55371	5973	8062	1349	15384
30/400H/OPP/200/30/5/M	182	1.8	852	55371	5973	8062	1349	15384
30/400H/OPP/200/35/5/M	183	6.3	852	55371	5973	8062	1349	15384
30/400H/OPP/200/40/5/M	184	10.1	852	67504	7308	8062	1349	16719
30/400H/OPP/200/45/5/M	185	12.4	852	67504	7308	8062	1349	16719
30/400H/OPP/250/25/5/M	186	3.4	688	47167	5089	6867	1149	13105
30/400H/OPP/250/30/5/M	187	4.2	688	47167	5089	6867	1149	13105
30/400H/OPP/250/35/5/M	188	1.9	688	47167	5089	6867	1149	13105
30/400H/OPP/250/40/5/M	189	3.9	688	57504	6225	6867	1149	14241
30/400H/OPP/250/45/5/M	190	6.8	688	57504	6225	6867	1149	14241
30/400H/STG/100/25/5/M	191	27.7	1704	104589	11283	15228	2548	29059
30/400H/STG/100/30/5/M	192	28.7	1704	104589	11283	15228	2548	29059
30/400H/STG/100/35/5/M	193	27.2	1704	104589	11283	15228	2548	29059

Table 22 Costs of New Systems

SYSTEM CODE	CASE NO.	VI <sub>15</sub>	ENERGY USE (kwh/mi/yr) x10 <sup>6</sup>	INITIAL COST		ANNUAL COST		TOTAL COSTS (\$/mi/yr)
				TOTAL (\$/mi)	ANNUAL (\$/mi/yr)	ENERGY (\$/mi/yr)	MAINTEN- ANCE (\$/mi/yr)	
30/400H/STG/100/40/5/M	194	25.7	1704	127508	13804	15228	2548	31580
30/400H/STG/100/45/5/M	195	24.7	1704	127508	13804	15228	2548	31586
30/400H/STG/150/25/5/M	196	19.4	1147	73827	7964	10749	1799	20511
30/400H/STG/150/30/5/M	197	20.2	1147	73827	7964	10749	1799	20511
30/400H/STG/150/35/5/M	198	20.2	1147	73827	7964	10749	1799	20511
30/400H/STG/150/40/5/M	199	20.6	1147	90005	9744	10749	1799	22292
30/400H/STG/150/45/5/M	200	20.5	1147	90005	9744	10749	1799	22292
30/400H/STG/200/25/5/M	201	12.9	852	55371	5973	8062	1349	15384
30/400H/STG/200/30/5/M	202	15.9	852	55371	5973	8062	1349	15384
30/400H/STG/200/35/5/M	203	16.7	852	55371	5973	8062	1349	15384
30/400H/STG/200/40/5/M	204	16.8	852	67504	7308	8062	1349	16719
30/400H/STG/200/45/5/M	205	17.0	852	67504	7308	8062	1349	16719
30/400H/STG/250/25/5/M	206	7.3	688	47167	5089	6867	1149	13105
30/400H/STG/250/30/5/M	207	11.9	688	47167	5089	6867	1149	13105
30/400H/STG/250/35/5/M	208	13.8	688	47167	5089	6867	1149	13105
30/400H/STG/250/40/5/M	209	14.7	688	57504	6225	6867	1149	14241
30/400H/STG/250/45/5/M	210	15.3	688	57504	6225	6867	1149	14241

Table 22 Costs of New Systems

SYSTEM CODE	CASE NO.	VI <sub>15</sub>	ENERGY USE (kwh/mi./yr) x10 <sup>6</sup>	INITIAL COST		ANNUAL COST		TOTAL COSTS (\$/mi./yr)
				TOTAL (\$/mi)	ANNUAL (\$/mi./yr)	ENERGY (\$/mi./yr)	MAINTEN- ANCE (\$/mi./yr)	
60/150H/OPP/100/20/11/M	211	10.1	639	80491	8632	5709	2548	16889
60/150H/OPP/100/25/11/M	212	11.4	639	104589	11283	5709	2548	19540
60/150H/OPP/100/30/11/M	213	13.2	639	104589	11283	5709	2548	19540
60/150H/OPP/100/35/11/M	214	13.5	639	104589	11283	5709	2548	19540
60/150H/OPP/100/40/11/M	215	13.5	639	109387	13804	5709	2548	22061
60/150H/OPP/150/20/11/M	216	4.1	430	56817	6093	4030	1799	11922
60/150H/OPP/150/25/11/M	217	4.7	430	73827	7965	4030	1799	13794
60/150H/OPP/150/30/11/M	218	8.0	430	73827	7965	4030	1799	13794
60/150H/OPP/150/35/11/M	219	8.9	430	73827	7965	4030	1799	13794
60/150H/OPP/150/40/11/M	220	9.8	430	77214	9744	4030	1799	15573
60/150H/OPP/200/20/11/M	221	2.6	319	42613	4570	3022	1349	8941
60/150H/OPP/200/25/11/M	222	3.2	319	56991	5973	3022	1349	10344
60/150H/OPP/200/30/11/M	223	4.2	319	56991	5973	3022	1349	10344
60/150H/OPP/200/35/11/M	224	6.2	319	56991	5973	3022	1349	10344
60/150H/OPP/200/40/11/M	225	7.2	319	57911	7308	3022	1349	11679
60/150H/OPP/250/20/11/M	226	2.3	258	36300	3893	2575	1149	7617

Table 22 Costs of New Systems

SYSTEM CODE	CASE NO.	VI <sub>15</sub>	ENERGY USE (kwh/mi/yr) x10 <sup>6</sup>	INITIAL COST		ANNUAL COST		TOTAL COSTS (\$/mi/yr)
				TOTAL (\$/mi)	ANNUAL (\$/mi/yr)	ENERGY (\$/mi/yr)	MAINTEN- ANCE (\$/mi/yr)	
60/150H/OPP/250/25/11/M	227	2.3	258	48547	5089	2575	1149	8813
60/150H/OPP/250/30/11/M	228	3.2	258	48547	5089	2575	1149	8813
60/150H/OPP/250/35/11/M	229	2.7	258	48547	5089	2575	1149	8813
60/150H/OPP/250/40/11/M	230	3.6	258	49331	6225	2575	1149	9949
60/150H/STG/100/20/11/M	231	10.6	639	80491	8632	5709	2548	16889
60/150H/STG/100/25/11/M	232	11.9	639	104689	11283	5709	2548	19540
60/150H/STG/100/30/11/M	233	13.1	639	104689	11283	5709	2548	19540
60/150H/STG/100/35/11/M	234	13.8	639	104589	11283	5709	2548	19540
60/150H/STG/100/40/11/M	235	13.2	639	109387	13804	5709	2548	22061
60/150H/STG/150/20/11/M	236	5.1	430	56817	6093	4030	1799	11922
60/150H/STG/150/25/11/M	237	7.1	430	73827	7965	4030	1799	13794
60/150H/STG/150/30/11/M	238	8.8	430	73827	7965	4030	1799	13794
60/150H/STG/150/35/11/M	239	9.2	430	73827	7965	4030	1799	13794
60/150H/STG/150/40/11/M	240	10.3	430	77214	9744	4030	1799	15573
60/150H/STG/200/20/11/M	241	4.0	319	42613	4570	3022	1349	8941
60/150H/STG/200/25/11/M	242	5.4	319	56991	5973	3022	1349	10344

Table 22 Costs of New Systems

SYSTEM CODE	CASE NO.	VI <sub>15</sub>	ENERGY USE (kwh/mi/yr) x10 <sup>6</sup>	INITIAL COST		ANNUAL COST		TOTAL COSTS (\$/mi/yr)
				TOTAL (\$/mi)	ANNUAL (\$/mi/yr)	ENERGY (\$/mi/yr)	MAINTEN- ANCE (\$/mi/yr)	
60/150H/STG/200/30/11/M	243	6.3	319	56991	5973	3022	1349	10344
60/150H/STG/200/35/11/M	244	6.9	319	56991	5973	3022	1349	10344
60/150H/STG/200/40/11/M	245	8.0	319	57911	7308	3022	1349	11679
60/150H/STG/250/20/11/M	246	2.9	258	36300	3893	2575	1149	7617
60/150H/STG/250/25/11/M	247	3.7	258	48547	5089	2575	1149	8813
60/150H/STG/250/30/11/M	248	4.8	258	48547	5089	2575	1149	8813
60/150H/STG/250/35/11/M	249	5.4	258	48547	5089	2575	1149	8813
60/150H/STG/250/40/11/M	250	6.8	258	49331	6225	2575	1149	9949

Table 22 Costs of New Systems

SYSTEM CODE	CASE NO.	VI <sub>15</sub>	ENERGY USE (kwh/mi <sup>2</sup> /yr) x10 <sup>6</sup>	INITIAL COST		ANNUAL COST		TOTAL COSTS (\$/mi/yr)
				TOTAL (\$/mi)	ANNUAL (\$/mi/yr)	ENERGY (\$/mi/yr)	MAINTEN- ANCE (\$/mi/yr)	
30/150H/ss/50/20/5/M	251	9.1	644	78913	8463	5597	2498	16558
30/150H/ss/50/25/5/M	252	11.4	644	102538	11062	5597	2498	19157
30/150H/ss/50/30/5/M	253	13.0	644	102538	11062	5597	2498	19157
30/150H/ss/50/35/5/M	254	13.2	644	102538	11062	5597	2498	19157
30/150H/ss/50/40/5/M	255	13.6	644	107242	13533	5597	2498	21628
30/150H/ss/100/20/5/M	256	6.3	319	40246	4316	2854	1274	8444
30/150H/ss/100/25/5/M	257	8.6	319	52294	5642	2854	1274	9769
30/150H/ss/100/30/5/M	258	10.7	319	52294	5642	2854	1274	9769
30/150H/ss/100/35/5/M	259	11.0	319	52294	5642	2854	1274	9769
30/150H/ss/100/40/5/M	260	10.6	319	54693	6902	2854	1274	11030
30/150H/ss/150/20/5/M	261	4.1	215	28409	3047	2015	899	5961
30/150H/ss/150/25/5/M	262	3.6	215	36914	3982	2015	899	6896
30/150H/ss/150/30/5/M	263	7.3	215	36914	3982	2015	899	6896
30/150H/ss/150/35/5/M	264	6.4	215	36914	3982	2015	899	6896
30/150H/ss/150/40/5/M	265	7.7	215	38607	4872	2015	899	7786
30/150H/ss/200/20/5/M	266	2.2	160	21307	2285	1511	674	4470

Table 22 Costs of New Systems

SYSTEM CODE	CASE NO.	VI <sub>15</sub>	ENERGY USE (kwh/mi <sup>6</sup> /yr) x10	INITIAL COST		ANNUAL COST		TOTAL COSTS (\$/mi/yr)
				TOTAL (\$/mi)	ANNUAL (\$/mi/yr)	ENERGY (\$/mi/yr)	MAINTEN- ANCE (\$/mi/yr)	
30/150H/55/200/25/5/M	267	3.2	160	27685	2987	1511	674	5172
30/150H/55/200/30/5/M	268	4.8	160	27685	2987	1511	674	5172
30/150H/55/200/35/5/M	269	6.0	160	27685	2987	1511	674	5172
30/150H/55/200/40/5/M	270	6.4	160	28955	3653	1511	674	5838
30/150H/55/250/20/5/M	271	2.5	129	18150	1946	1287	575	3808
30/150H/55/250/25/5/M	272	2.1	129	23584	2544	1287	575	4406
30/150H/55/250/30/5/M	273	3.6	129	23584	2544	1287	575	4406
30/150H/55/250/35/5/M	274	3.7	129	23584	2544	1287	575	4406
30/150H/55/250/40/5/M	275	4.4	129	24666	3113	1287	575	4975
30/150H/OPP/100/20/5/M	276	13.7	639	80491	8632	5709	2548	16889
30/150H/OPP/100/25/5/M	277	14.7	639	104589	11283	5709	2548	19540
30/150H/OPP/100/30/5/M	278	16.0	639	104689	11283	5709	2548	19540
30/150H/OPP/100/35/5/M	279	16.3	639	104589	11283	5709	2548	19540
30/150H/OPP/100/40/5/M	280	15.6	639	109387	13804	5709	2548	22061
30/150H/OPP/150/20/5/M	281	4.7	430	56817	6093	4030	1799	11922
30/150H/OPP/150/25/5/M	282	8.8	430	73827	7965	4030	1799	13794

Table 22 Costs of New Systems

SYSTEM CODE	CASE NO.	VI <sub>15</sub>	ENERGY USE (kwh/mi/yr) x10 <sup>6</sup>	INITIAL COST		ANNUAL COST		TOTAL COSTS (\$/mi/yr)
				TOTAL (\$/mi)	ANNUAL (\$/mi/yr)	ENERGY (\$/mi/yr)	MAINTEN- ANCE (\$/mi/yr)	
30/150H/OPP/150/30/5/M	283	10.4	430	73827	7965	4030	1799	13794
30/150H/OPP/150/35/5/M	284	11.9	430	78827	7965	4030	1799	13794
30/150H/OPP/150/40/5/M	285	13.2	430	71214	9744	4030	1799	15573
30/150H/OPP/200/20/5/M	286	2.0	319	42613	4570	3022	1349	8941
30/150H/OPP/200/25/5/M	287	4.8	319	56991	5973	3022	1349	10344
30/150H/OPP/200/30/5/M	288	6.8	319	56991	5973	3022	1349	10344
30/150H/OPP/200/35/5/M	289	8.3	319	56991	5973	3022	1349	10344
30/150H/OPP/200/40/5/M	290	6.6	319	57911	7308	3022	1349	11679
30/150H/OPP/250/20/5/M	291	1.9	258	36300	3893	2575	1149	7617
30/150H/OPP/250/25/5/M	292	3.7	258	48547	5089	2575	1149	8813
30/150H/OPP/250/30/5/M	293	5.3	258	48547	5089	2575	1149	8813
30/150H/OPP/250/35/5/M	294	6.0	258	48547	5089	2575	1149	8813
30/150H/OPP/250/40/5/M	295	5.9	258	49331	6225	2575	1149	9949
30/150H/STG/100/20/5/M	296	13.6	639	80991	8632	5709	2548	16889
30/150H/STG/100/25/5/M	297	16.4	639	104589	11283	5709	2548	19540
30/150H/STG/100/30/5/M	298	16.4	639	104589	11283	5709	2548	19540

Table 22 Costs of New Systems

SYSTEM CODE	CASE NO.	VI <sub>15</sub>	ENERGY USE (kwh/mi/yr) x10 <sup>6</sup>	INITIAL COST		ANNUAL COST		TOTAL COSTS (\$/mi/yr)
				TOTAL (\$/mi)	ANNUAL (\$/mi/yr)	ENERGY (\$/mi/yr)	MAINTEN- ANCE (\$/mi/yr)	
30/150H/STG/100/35/5/M	299	16.2	639	104509	11283	5709	2548	19546
30/150H/STG/100/40/5/M	300	15.0	639	109387	13804	5709	2548	22061
30/150H/STG/150/20/5/M	301	6.3	430	56817	6093	4030	1799	11922
30/150H/STG/150/25/5/M	302	10.2	430	73827	7965	4030	1799	13794
30/150H/STG/150/30/5/M	303	12.8	430	73827	7965	4030	1799	13794
30/150H/STG/160/35/5/M	304	11.2	430	73827	7965	4030	1799	13794
30/150H/STG/150/40/5/M	305	12.3	430	77214	9744	4030	1799	15573
30/150H/STG/200/20/5/M	306	6.5	319	42613	4570	3022	1349	8941
30/150H/STG/200/25/5/M	307	8.0	319	56991	5973	3022	1349	10340
30/150H/STG/200/30/5/M	308	11.9	319	56991	5973	3022	1349	10344
30/150H/STG/200/35/5/M	309	11.2	319	56991	5973	3022	1349	10344
30/150H/STG/200/40/5/M	310	11.4	319	57911	7308	3022	1349	11679
30/150H/STG/250/20/5/M	311	1.9	258	36300	3893	2575	1149	7617
30/150H/STG/250/25/5/M	312	6.2	258	48547	5089	2575	1149	8813
30/150H/STG/250/30/5/M	313	7.2	258	48547	5089	2575	1149	8813
30/150H/STG/250/35/5/M	314	8.4	258	48547	5089	2575	1149	8813
30/150H/STG/250/40/5/M	315	9.3	258	49331	6225	2575	1149	9949

Table 22 Costs of New Systems

SYSTEM CODE	CASE NO.	VI <sub>15</sub>	ENERGY USE (kwh/mi/yr) x10 <sup>6</sup>	INITIAL COST		ANNUAL COST		TOTAL COSTS (\$/mi/yr)
				TOTAL (\$/mi)	ANNUAL (\$/mi/yr)	ENERGY (\$/mi/yr)	MAINTEN- ANCE (\$/mi/yr)	
60/175M/OPP/100/20/11/M	316	5.5	746	73943	7912	6662	751	15325
60/175M/OPP/100/25/11/M	317	4.4	746	98040	10563	6662	751	17976
60/175M/OPP/100/30/11/M	318	6.8	746	98040	10563	6662	751	17976
60/175M/OPP/100/35/11/M	319	6.8	746	98040	10563	6662	751	17976
60/175M/OPP/100/40/11/M	320	7.1	746	120966	13084	6662	751	20497
60/175M/OPP/150/20/11/M	321	2.2	502	52195	5585	4702	531	10818
60/175M/OPP/150/25/11/M	322	3.2	502	69205	7456	4702	531	12689
60/175M/OPP/150/30/11/M	323	3.1	502	69205	7456	4702	531	12689
60/175M/OPP/150/35/11/M	324	3.1	502	69205	7456	4702	531	12689
60/175M/OPP/150/40/11/M	325	3.9	502	85383	9235	4702	531	14468
60/175M/OPP/200/20/11/M	326	1.7	373	39146	4189	3527	398	8114
60/175M/OPP/200/25/11/M	327	1.7	373	51904	5592	3527	398	9517
60/175M/OPP/200/30/11/M	328	2.2	373	51904	5592	3527	398	9517
60/175M/OPP/200/35/11/M	329	2.3	373	51904	5592	3527	398	9517
60/175M/OPP/200/40/11/M	330	2.1	373	64038	6927	3527	398	10852
60/175M/OPP/250/20/11/M	331	1.5	301	33347	3568	3004	339	6911

Table 22 Costs of New Systems

SYSTEM CODE	CASE NO.	VI <sub>15</sub>	ENERGY USE (kwh/mi/yr) x10 <sup>6</sup>	INITIAL COST		ANNUAL COST		TOTAL COSTS (\$/mi/yr)
				TOTAL (\$/mi)	ANNUAL (\$/mi/yr)	ENERGY (\$/mi/yr)	MAINTEN- ANCE (\$/mi/yr)	
60/175M/OPP/250/25/11/M	332	0.9	301	44214	4764	3004	339	8107
60/175M/OPP/250/30/11/M	333	1.5	301	44214	4764	3004	339	8107
60/175M/OPP/250/35/11/M	334	1.4	301	44214	4764	3004	339	8107
60/175M/OPP/250/40/11/M	335	1.6	301	54550	5900	3004	339	9243
60/175M/STG/100/20/11/M	336	6.0	746	73943	7912	6662	751	15325
60/175M/STG/100/25/11/M	337	7.6	746	98040	10563	6662	751	17976
60/175M/STG/100/30/11/M	338	7.4	746	98040	10563	6662	751	17976
60/175M/STG/100/35/11/M	339	8.0	746	98040	10563	6662	751	17976
60/175M/STG/100/40/11/M	340	7.2	746	120960	13084	6662	751	20497
60/175M/STG/150/20/11/M	341	3.1	502	52195	5585	4702	531	10818
60/175M/STG/150/25/11/M	342	4.2	502	69205	7456	4702	531	12689
60/175M/STG/150/30/11/M	343	3.7	502	69205	7456	4702	531	12689
60/175M/STG/150/35/11/M	344	3.7	502	69205	7456	4702	531	12689
60/175M/STG/150/40/11/M	345	5.1	502	85383	9235	4702	531	14468
60/175M/STG/200/20/11/M	346	1.9	373	39146	4189	3527	398	8114
60/175M/STG/200/25/11/M	347	2.3	373	51904	5592	3527	398	9517

## Table 22 Costs of New Systems

[illegible]

Table 22 Costs of New Systems

SYSTEM CODE	CASE NO.	VI <sub>15</sub>	ENERGY USE (kwh/mi/yr) x10 <sup>6</sup>	INITIAL COST		ANNUAL COST		TOTAL COSTS (\$/mi/yr)
				TOTAL (\$/mi)	ANNUAL (\$/mi/yr)	ENERGY (\$/mi/yr)	MAINTEN- ANCE (\$/mi/yr)	
30/175M/SS/50/20/5/M	356	6.8	753	72493	7757	6531	737	15025
30/175M/SS/50/25/5/M	357	8.6	753	96118	10356	6531	737	17624
30/175M/SS/50/30/5/M	358	10.1	753	96118	10356	6531	737	17624
30/175M/SS/50/35/5/M	359	10.7	753	96118	10356	6531	737	17624
30/175M/SS/50/40/5/M	360	10.4	753	118588	12827	6531	737	20095
30/175M/SS/100/20/5/M	361	3.7	373	36971	3956	3331	376	7663
30/175M/SS/100/25/5/M	362	4.6	373	49020	5282	3331	376	8989
30/175M/SS/100/30/5/M	363	6.4	373	49020	5282	3331	376	8989
30/175M/SS/100/35/5/M	364	7.1	373	49020	5282	3331	376	8989
30/175M/SS/100/40/5/M	365	7.1	373	60480	6542	3331	376	10249
30/175M/SS/150/20/5/M	366	1.3	251	26097	2793	2351	265	5409
30/175M/SS/150/25/5/M	367	1.8	251	34602	3728	2351	265	6344
30/175M/SS/150/30/5/M	368	3.5	251	34602	3728	2351	265	6344
30/175M/SS/150/35/5/M	369	3.8	251	34602	3728	2351	265	6344
30/175M/SS/150/40/5/M	370	4.5	251	42692	4618	2351	265	7234
30/175M/SS/200/20/5/M	371	1.5	186	19573	2094	1763	199	4056

Table 22 Costs of New Systems

SYSTEM CODE	CASE NO.	VI <sub>15</sub>	ENERGY USE (kwh/mi/yr) x10 <sup>6</sup>	INITIAL COST		ANNUAL COST		TOTAL COSTS (\$/mi/yr)
				TOTAL (\$/mi)	ANNUAL (\$/mi/yr)	ENERGY (\$/mi/yr)	MAINTEN- ANCE (\$/mi/yr)	
30/175M/SS/200/25/5/M	372	1.3	186	25952	2796	1763	199	4758
30/175M/SS/200/30/5/M	373	1.9	186	25952	2796	1763	199	4758
30/175M/SS/200/35/5/M	374	2.1	186	25952	2796	1763	199	4758
30/175M/SS/200/40/5/M	375	2.4	186	32019	3463	1763	199	5425
30/175M/SS/250/20/5/M	376	1.2	151	16673	1784	1502	170	3456
30/175M/SS/250/25/5/M	377	0.9	151	22107	2382	1502	170	4054
30/175M/SS/250/30/5/M	378	1.2	151	22107	2382	1502	170	4054
30/175M/SS/250/35/5/M	379	1.9	151	22107	2382	1502	170	4054
30/175M/SS/250/40/5/M	380	1.4	151	27275	2950	1502	170	4622
30/175M/OPP/100/20/5/M	381	4.2	746	73943	7912	6662	751	15325
30/175M/OPP/100/25/5/M	382	7.1	746	98040	10563	6662	751	17976
30/175M/OPP/100/30/5/M	383	8.2	746	98040	10563	6662	751	17976
30/175M/OPP/100/35/5/M	384	8.8	746	98040	10563	6662	751	17976
30/175M/OPP/100/40/5/M	385	9.8	746	120960	13084	6662	751	20997
30/175M/OPP/150/20/5/M	386	2.9	502	52195	5585	4702	531	10818
30/175M/OPP/150/25/5/M	387	3.6	502	69205	7456	4702	531	12689

Table 22 Costs of New Systems

SYSTEM CODE	CASE NO.	VI <sub>15</sub>	ENERGY USE (kwh/mi/yr) x10 <sup>6</sup>	INITIAL COST		ANNUAL COST		TOTAL COSTS (\$/mi/yr)
				TOTAL (\$/mi)	ANNUAL (\$/mi/yr)	ENERGY (\$/mi/yr)	MAINTEN- ANCE (\$/mi/yr)	
30/175M/OPP/150/30/5/M	388	5.1	502	69205	7456	4702	531	12689
30/175M/OPP/150/35/5/M	389	6.7	502	69205	7456	4702	531	12689
30/175M/OPP/150/40/5/M	390	7.2	502	85383	9235	4702	531	14468
30/175M/OPP/200/20/5/M	391	1.6	373	39146	4189	3527	398	8114
30/175M/OPP/200/25/5/M	392	2.4	373	51904	5592	3527	398	9517
30/175M/OPP/200/30/5/M	393	3.6	373	51904	5592	3527	398	9517
30/175M/OPP/200/35/5/M	394	3.7	373	51904	5592	3527	398	9517
30/175M/OPP/200/40/5/M	395	3.6	373	64638	6927	3527	398	10852
30/175M/OPP/250/20/5/M	396	1.8	301	33347	3568	3004	339	6911
30/175M/OPP/250/25/5/M	397	1.6	301	44214	4764	3004	339	8107
30/175M/OPP/250/30/5/M	398	2.7	301	44214	4764	3004	339	8107
30/175M/OPP/250/35/5/M	399	3.4	301	44214	4764	3004	339	8107
30/175M/OPP/250/40/5/M	400	2.5	301	54550	5906	3004	339	9243
30/175M/STG/100/20/5/M	401	4.8	746	73943	7912	6662	751	15325
30/175M/STG/100/25/5/M	402	7.5	746	98040	10563	6662	751	17976
30/175M/STG/100/30/5/M	403	8.9	746	98040	10563	6662	751	17976

Table 22 Costs of New Systems

SYSTEM CODE	CASE NO.	VI <sub>15</sub>	ENERGY USE (kwh/mi/yr) x10 <sup>6</sup>	INITIAL COST		ANNUAL COST		TOTAL COSTS (\$/mi/yr)
				TOTAL (\$/mi)	ANNUAL (\$/mi/yr)	ENERGY (\$/mi/yr)	MAINTEN- ANCE (\$/mi/yr)	
30/175M/STG/100/35/5/M	404	9.7	746	98040	10563	6662	751	17976
30/175M/STG/100/40/5/M	405	10.1	746	120960	13084	6662	751	20497
30/175M/STG/150/20/5/M	406	2.6	502	52195	5585	4702	531	10818
30/175M/STG/150/25/5/M	407	5.1	502	69205	7456	4702	531	12689
30/175M/STG/150/30/5/M	408	6.8	502	69205	7456	4702	531	12689
30/175M/STG/150/35/5/M	409	7.6	502	69205	7456	4702	531	12689
30/175M/STG/150/40/5/M	410	8.1	502	86383	9235	4702	531	14468
30/175M/STG/200/20/5/M	411	2.9	373	39146	4189	3527	398	8114
30/175M/STG/200/25/5/M	412	4.8	373	51904	5592	3527	398	9517
30/175M/STG/200/30/5/M	413	5.2	373	51904	5592	3527	398	9517
30/175M/STG/200/35/5/M	414	5.3	373	51904	5592	3527	398	9517
30/175M/STG/200/40/5/M	415	5.7	373	64038	6927	3527	398	10852
30/175M/STG/250/20/5/M	416	1.5	301	33347	3568	3004	339	6911
30/175M/STG/250/25/5/M	417	3.0	301	44214	4764	3004	339	8107
30/175M/STG/250/30/5/M	418	3.6	301	44214	4764	3004	339	8107
30/175M/STG/250/35/5/M	419	3.9	301	44214	4764	3004	339	8107
30/175M/STG/250/40/5/M	420	4.0	301	54550	5900	3004	339	9243

Table 23 Benefit Cost Ratios of New Systems

SYSTEM CODE	CASE NO.	VI <sub>15</sub>	COSTS (\$/mi/yr)	AREA (TYPE)	DENSITY (People/sq mi)	VOLUME (ADT)	BENEFITS (\$/mi/yr)	BENEFIT COST RATIO
60/400M/STG/100/35/11/M	23	13.4	26543		30000	20000	27208	1.03
60/400M/STG/100/40/11/M	24	13.8	29043		"	"	29476	1.02
60/400M/STG/100/45/11/M	25	13.8	29043		"	"	29476	1.02
60/400M/STG/150/45/11/M	30	10.7	20514		"	"	21995	1.07
60/400M/STG/200/45/11/M	35	7.8	15387		"	"	15434	1.00
30/400M/SS/50/35/5/M	43	13.1	26022		"	"	27208	1.05
30/400M/SS/50/40/5/M	44	13.9	28493		"	"	29476	1.03
30/400M/SS/50/45/5/M	45	14.1	28493		"	"	29476	1.03
30/400M/SS/100/30/5/M	47	7.4	13271		"	"	13592	1.02
30/400M/SS/100/35/5/M	48	9.1	13271		"	"	18152	1.37
30/400M/SS/100/40/5/M	49	9.6	14532		"	"	20410	1.40
30/400M/SS/100/45/5/M	50	9.8	14532		"	"	20410	1.40
30/400M/SS/150/35/5/M	53	5.7	9367		"	"	11334	1.21

Table 23 Benefit Cost Ratios of New Systems

SYSTEM CODE	CASE NO.	VI <sub>15</sub>	COSTS (\$/mi/yr)	AREA (TYPE)	DENSITY (People/sq mi)	VOLUME (ADT)	BENEFITS (\$/mi/yr)	BENEFIT COST RATIO
30/400M/SS/150/40/5/M	54	6.5	10257		30000	20000	13592	1.33
30/400M/SS/150/45/5/M	55	7.3	10257		"	"	13592	1.33
30/400M/SS/200/40/5/M	59	4.4	7693		"	"	7721	1.00
30/400M/SS/200/45/5/M	60	5.3	7693		"	"	9076	1.18
30/400M/SS/250/45/5/M	65	3.9	6554		"	"	6818	1.04
30/400M/OPP/100/30/5/M	67	12.8	26543		"	"	27208	1.03
30/400M/OPP/100/35/5/M	68	14.0	26543		"	"	29476	1.11
30/400M/OPP/100/40/5/M	69	14.7	29043		"	"	31740	1.09
30/400M/OPP/100/45/5/M	70	15.4	29043		"	"	31766	1.09
30/400M/OPP/150/45/5/M	75	10.8	20514		"	"	22220	1.08
30/400M/STG/100/25/5/M	86	15.2	26543		"	"	31753	1.20
30/400M/STG/100/30/5/M	87	16.3	26543		"	"	31822	1.20
30/400M/STG/100/35/5/M	88	16.3	26543		"	"	31822	1.20
30/400M/STG/100/40/5/M	89	16.3	29043		"	"	31822	1.10

Table 23 Benefit Cost Ratios of New Systems

SYSTEM CODE	CASE NO.	VI <sub>15</sub>	COSTS (\$/mi/yr)	AREA (TYPE)	DENSITY (People/sq mi)	VOLUME (ADT)	BENEFITS (\$/mi/yr)	BENEFIT COST RATIO
30/400M/STG/100/45/5/M	90	16.2	29043		30000	20000	31816	1.10
30/400M/STG/150/30/5/M	92	11.0	18735		"	"	22674	1.21
30/400M/STG/150/35/5/M	93	12.3	18735		"	"	24942	1.33
30/400M/STG/150/40/5/M	94	13.0	20514		"	"	27208	1.33
30/400M/STG/150/45/5/M	95	13.2	20514		"	"	27208	1.33
30/400M/STG/200/35/5/M	98	9.0	14052		"	"	18152	1.29
30/400M/STG/200/40/5/M	99	10.1	15387		"	"	20410	1.33
30/400M/STG/200/45/5/M	100	10.7	15387		"	"	22674	1.47
30/400M/STG/250/40/5/M	104	7.2	13106		"	"	13592	1.04
30/400M/STG/250/45/5/M	105	8.3	13106		"	"	15894	1.21
60/400H/OPP/100/25/11/M	106	16.0	29059		"	"	31803	1.09
60/400H/OPP/100/30/11/M	107	17.7	29059		"	"	31911	1.10
60/400H/OPP/100/35/11/M	108	17.7	29059		"	"	31911	1.10

Table 23 Benefit Cost Ratios of New Systems

SYSTEM CODE	CASE NO.	VI <sub>15</sub>	COSTS (\$/mi/yr)	AREA (TYPE)	DENSITY (People/sq mi)	VOLUME (ADT)	BENEFITS (\$/mi/yr)	BENEFIT COST RATIO
60/400H/OPP/100/40/11/M	109	18.0	31580		30000	20000	31930	1.01
60/400H/OPP/100/45/11/M	110	18.0	31580		"	"	31930	1.01
60/400H/OPP/150/35/11/M	113	12.6	20511		"	"	27208	1.33
60/400H/OPP/150/40/11/M	114	13.9	22292		"	"	29476	1.32
60/400H/OPP/150/45/11/M	115	14.7	22292		"	"	31740	1.42
60/400H/OPP/200/40/11/M	119	8.5	16719		"	"	18152	1.09
60/400H/OPP/200/45/11/M	120	10.4	16719		"	"	20410	1.22
60/400H/STG/100/25/11/M	126	16.5	29059		"	"	31835	1.10
60/400H/STG/100/30/11/M	127	19.1	29059		"	"	32000	1.10
60/400H/STG/100/35/11/M	128	18.7	29059		"	"	31975	1.10
60/400H/STG/100/40/11/M	129	18.2	31580		"	"	31943	1.01
60/400H/STG/100/45/11/M	130	18.5	31580		"	"	31962	1.01
60/400H/STG/150/30/11/M	132	13.1	20511		"	"	27208	1.33
60/400H/STG/150/35/11/M	133	14.2	20511		"	"	29476	1.44

Table 23 Benefit Cost Ratios of New Systems

SYSTEM CODE	CASE NO.	VI <sub>15</sub>	COSTS (\$/mi/yr)	AREA (TYPE)	DENSITY (People/sq mi)	VOLUME (ADT)	BENEFITS (\$/mi/yr)	BENEFIT COST RATIO
60/400H/STG/150/40/11/M	134	15.0	22292		30 000	20000	31740	1.42
60/400H/STG/150/45/11/M	135	15.5	22292		"	"	31772	1.43
60/400H/STG/200/30/11/M	137	8.2	15384		"	"	15894	1.03
60/400H/STG/200/35/11/M	138	10.9	15384		"	"	22674	1.47
60/400H/STG/200/40/11/M	139	12.5	16719		"	"	27208	1.63
60/400H/STG/200/45/11/M	140	12.7	16719		"	"	27208	1.63
60/400H/STG/250/35/11/M	143	8.1	13105		"	"	15894	1.21
60/400H/STG/250/40/11/M	144	9.3	14241		"	"	18152	1.27
60/400H/STG/250/45/11/M	145	10.8	14241		"	"	22674	1.59
30/400H/SS/50/25/5/M	146	23.2	28489		"	"	32260	1.32
30/400H/SS/50/30/5/M	147	22.6	28489		"	"	32222	1.13
30/400H/SS/50/35/5/M	148	24.4	28489		"	"	32336	1.14
30/400H/SS/50/40/5/M	149	24.2	30960		"	"	32324	1.04

Table 23 Benefit Cost Ratios of New Systems

SYSTEM CODE	CASE NO.	VI <sub>15</sub>	COSTS (\$/mi/yr)	AREA (TYPE)	DENSITY (People/sq mi)	VOLUME (ADT)	BENEFITS (\$/mi/yr)	BENEFIT COST RATIO
30/400H/SS/50/45/5/M	150	24.3	30960		30000	20000	32330	1.04
30/400H/SS/100/25/5/M	151	13.0	14530		"	"	27208	1.87
30/400H/SS/100/30/5/M	152	15.0	14530		"	"	31740	2.18
30/400H/SS/100/35/5/M	153	16.6	14530		"	"	31842	2.19
30/400H/SS/100/40/5/M	154	16.9	15790		"	"	31860	2.02
30/400H/SS/100/45/5/M	155	17.1	15790		"	"	31873	2.02
30/400H/SS/150/25/5/M	156	6.1	10255		"	"	11334	1.11
30/400H/SS/150/30/5/M	157	9.8	10255		"	"	20410	1.99
30/400H/SS/150/35/5/M	158	11.5	10255		"	"	24942	2.43
30/400H/SS/150/40/5/M	159	12.9	11145		"	"	27208	2.44
30/400H/SS/150/45/5/M	160	13.5	11145		"	"	29476	2.64
30/400H/SS/200/35/5/M	163	6.2	7692		"	"	11334	1.47
30/400H/SS/200/40/5/M	164	8.1	8359		"	"	15894	1.90
30/400H/SS/200/45/5/M	165	9.5	8359		"	"	20410	2.44

Table 23 Benefit Cost Ratios of New Systems

SYSTEM CODE	CASE NO.	VI <sub>15</sub>	COSTS (\$/mi/yr)	AREA (TYPE)	DENSITY (People/sq mi)	VOLUME (ADT)	BENEFITS (\$/mi/yr)	BENEFIT COST RATIO
30/400H/SS/250/45/5/M	170	5.8	7122		30000	20000	11334	1.59
30/400H/OPP/100/25/5/M	171	24.6	29059		"	"	32349	1.11
30/400H/OPP/100/30/5/M	172	25.6	29059		"	"	32413	1.12
30/400H/OPP/100/35/5/M	173	25.8	29059		"	"	32426	1.16
30/400H/OPP/100/40/5/M	174	25.5	31580		"	"	32407	1.03
30/400H/OPP/100/45/5/M	175	24.7	31580		"	"	32356	1.02
30/400H/OPP/150/30/5/M	177	12.8	20511		"	"	27208	1.32
30/400H/OPP/150/35/5/M	178	15.9	20511		"	"	31797	1.55
30/400H/OPP/150/40/5/M	179	17.5	22292		"	"	31898	1.43
30/400H/OPP/150/45/5/M	180	17.9	22292		"	"	31924	1.43
30/400H/OPP/200/40/5/M	184	10.1	16719		"	"	20410	1.22
30/400H/OPP/200/45/5/M	185	12.4	16719		"	"	24942	1.49
30/400H/STG/100/25/5/M	191	27.7	29059		"	"	32546	1.12
30/400H/STG/100/30/5/M	192	28.7	29059		"	"	32610	1.12

Table 23 Benefit Cost Ratios of New Systems

SYSTEM CODE	CASE NO.	VI <sub>15</sub>	COSTS (\$/mi/yr)	AREA (TYPE)	DENSITY (People/sq mi)	VOLUME (ADT)	BENEFITS (\$/mi/yr)	BENEFIT COST RATIO
30/400H/STG/100/35/5/M	193	27.2	29059		30000	20000	32514	1.12
30/400H/STG/100/40/5/M	194	25.7	31580		"	"	32419	1.03
30/400H/STG/100/45/5/M	195	24.7	31586		"	"	32356	1.02
30/400H/STG/150/25/5/M	196	19.4	20511		"	"	32019	1.56
30/400H/STG/150/30/5/M	197	20.2	20511		"	"	32070	1.56
30/400H/STG/150/35/5/M	198	20.2	20511		"	"	32070	1.56
30/400H/STG/150/40/5/M	199	20.6	22292		"	"	32095	1.44
30/400H/STG/150/45/5/M	200	20.5	22292		"	"	32089	1.44
30/400H/STG/200/25/5/M	201	12.9	15384		"	"	27208	1.77
30/400H/STG/200/30/5/M	202	15.9	15384		"	"	31797	2.07
30/400H/STG/200/35/5/M	203	16.7	15384		"	"	31848	2.07
30/400H/STG/200/40/5/M	204	16.8	16719		"	"	31854	1.91
30/400H/STG/200/45/5/M	205	17.0	16719		"	"	31867	1.91
30/400H/STG/250/25/5/M	206	7.3	13105		"	"	13592	1.03

Table 23 Benefit Cost Ratios of New Systems

SYSTEM CODE	CASE NO.	VI <sub>15</sub>	COSTS (\$/mi/yr)	AREA (TYPE)	DENSITY (People/sq mi)	VOLUME (ADT)	BENEFITS (\$/mi/yr)	BENEFIT COST RATIO
30/400H/STG/250/30/5/M	207	11.9	13105		30000	20000	24942	1.90
30/400H/STG/250/35/5/M	208	13.8	13105		"	"	29476	2.25
30/400H/STG/250/40/5/M	209	14.7	14241		"	"	31740	2.23
30/400H/STG/250/45/5/M	210	15.3	14241		"	"	31740	2.23
60/150H/OPP/100/20/11/M	211	10.1	16889		"	"	20410	1.21
60/150H/OPP/100/25/11/M	212	11.4	19540		"	"	22674	1.16
60/150H/OPP/100/30/11/M	213	13.2	19540		"	"	27208	1.39
60/150H/OPP/100/35/11/M	214	13.5	19540		"	"	29476	1.51
60/150H/OPP/100/40/11/M	215	13.5	22061		"	"	29476	1.34
60/150H/OPP/150/30/11/M	218	8.0	13794		"	"	15894	1.15
60/150H/OPP/150/35/11/M	219	8.9	13794		"	"	18152	1.32
60/150H/OPP/150/40/11/M	220	9.8	15573		"	"	20410	1.31
60/150H/OPP/200/35/11/M	224	6.2	10344		"	"	11334	1.10

Table 23 Benefit Cost Ratios of New Systems

SYSTEM CODE	CASE NO.	VI <sup>15</sup>	COSTS (\$/mi/yr)	AREA (TYPE)	DENSITY (People/sq mi)	VOLUME (ADT)	BENEFITS (\$/mi/yr)	BENEFIT COST RATIO
60/150H/OPP/200/40/11/M	225	7.2	11679		30000	20000	13592	1.16
60/150H/STG/100/20/11/M	231	10.6	16889		"	"	22674	1.34
60/150H/STG/100/25/11/M	232	11.9	19540		"	"	24942	1.28
60/150H/STG/100/30/11/M	233	13.1	19540		"	"	27208	1.39
60/150H/STG/100/35/11/M	234	13.8	19540		"	"	29476	1.51
60/150H/STG/100/40/11/M	235	13.2	22061		"	"	27208	1.23
60/150H/STG/150/25/11/M	237	7.1	13794		"	"	13822	1.00
60/150H/STG/150/30/11/M	238	8.8	13794		"	"	18152	1.32
60/150H/STG/150/35/11/M	239	9.2	13794		"	"	18152	1.32
60/150H/STG/150/40/11/M	240	10.3	15573		"	"	20410	1.31
60/150H/STG/200/30/11/M	243	6.3	10344		"	"	11334	1.10
60/150H/STG/200/35/11/M	244	6.9	10344		"	"	13592	1.31
60/150H/STG/200/40/11/M	245	8.0	11679		"	"	15894	1.36
60/150H/STG/250/30/11/M	248	4.8	8813		"	"	9076	1.03

Table 23 Benefit Cost Ratios of New Systems

SYSTEM CODE	CASE NO.	VI <sub>15</sub>	COSTS (\$/mi/yr)	AREA (TYPE)	DENSITY (People/sq mi)	VOLUME (ADT)	BENEFITS (\$/mi/yr)	BENEFIT COST RATIO
60/150H/STG/250/35/11/M	249	5.4	8813		30 000	20 000	9076	1.03
60/150H/STG/250/40/11/M	250	6.8	9949		"	"	13592	1.37
30/150H/SS/50/20/5/M	251	9.1	16558		"	"	18152	1.10
30/150H/SS/50/25/5/M	252	11.4	19157		"	"	22674	1.18
30/150H/SS/50/30/5/M	253	13.0	19157		"	"	27208	1.42
30/150H/SS/50/35/5/M	254	13.2	19157		"	"	27208	1.42
30/150H/SS/50/40/5/M	255	13.6	21628		"	"	29476	1.36
30/150H/SS/100/20/5/M	256	6.3	8444		"	"	11334	1.34
30/150H/SS/100/25/5/M	257	8.6	9769		"	"	18152	1.86
30/150H/SS/100/30/5/M	258	10.7	9769		"	"	22674	2.32
30/150H/SS/100/35/5/M	259	11.0	9769		"	"	22674	2.32
30/150H/SS/100/40/5/M	260	10.6	11030		"	"	22674	2.06
30/150H/SS/150/20/5/M	261	4.1	5961		"	"	6818	1.14

Table 23 Benefit Cost Ratios of New Systems

SYSTEM CODE	CASE NO.	VI <sub>15</sub>	COSTS (\$/mi/yr)	AREA (TYPE)	DENSITY (People/sq mi)	VOLUME (ADT)	BENEFITS (\$/mi/yr)	BENEFIT COST RATIO
30 150H SS 150 30 5 M	263	7.3	6896		30000	20000	13592	1.97
30 150H SS 150 35 5 M	264	6.4	6896		"	"	11334	1.64
30 150H SS 150 40 5 M	265	7.7	7786		"	"	15894	2.04
30 150H SS 200 30 5 M	268	4.8	5172		"	"	9076	1.75
30 150H SS 200 35 5 M	269	6.0	5172		"	"	11334	2.19
30 150H SS 200 40 5 M	270	6.4	5838		"	"	11334	1.94
30 150H SS 250 30 5 M	273	3.6	4406		"	"	6818	1.55
30 150H SS 250 35 5 M	274	3.7	4406		"	"	6818	1.55
30 150H SS 250 40 5 M	275	4.4	4975		"	"	6818	1.37
30 150H OPP 100 20 5 M	276	13.7	16889		"	"	29476	1.75
30 150H OPP 100 25 5 M	277	14.7	19540		"	"	31740	1.62
30 150H OPP 100 30 5 M	278	16.0	19540		"	"	31803	1.63
30 150H OPP 100 35 5 M	279	16.3	19540		"	"	31822	1.63
30 150H OPP 100 40 5 M	280	15.6	22061		"	"	31778	1.44

Table 23 Benefit Cost Ratios of New Systems

SYSTEM CODE	CASE NO.	VI <sub>15</sub>	COSTS (\$/mi/yr)	AREA (TYPE)	DENSITY (People/sq mi)	VOLUME (ADT)	BENEFITS (\$/mi/yr)	BENEFIT COST RATIO
30 150H OPP 150 25 5 M	282	8.8	13794		30 000	20000	18152	1.32
30 150H OPP 150 30 5 M	283	10.4	13794		"	"	20410	1.48
30 150H OPP 150 35 5 M	284	11.9	13794		"	"	24942	1.81
30 150H OPP 150 40 5 M	285	13.2	15573		"	"	27208	1.75
30 150H OPP 200 30 5 M	288	6.8	10344		"	"	13592	1.31
30 150H OPP 200 35 5 M	289	8.3	10344		"	"	15894	1.54
30 150H OPP 200 40 5 M	290	6.6	11679		"	"	13592	1.16
30 150H OPP 250 30 5 M	293	5.3	8813		"	"	9076	1.03
30 150H OPP 250 35 5 M	294	6.0	8813		"	"	11334	1.29
30 150H OPP 250 40 5 M	295	5.9	9949		"	"	11334	1.14
30 150H STG 100 20 5 M	296	13.6	16889		"	"	29476	1.75
30 150H STG 100 25 5 M	297	16.4	19540		"	"	31829	1.63
30 150H STG 100 30 5 M	298	16.4	19540		"	"	31829	1.63
30 150H STG 100 35 5 M	299	16.2	19540		"	"	31816	1.63

Table 23 Benefit Cost Ratios of New Systems

SYSTEM CODE	CASE NO.	VI <sub>15</sub>	COSTS (\$/mi/yr)	AREA (TYPE)	DENSITY (People/sq mi)	VOLUME (ADT)	BENEFITS (\$/mi/yr)	BENEFIT COST RATIO
30 150H STG 100 40 5 M	300	15.0	22061		30000	20000	31740	1.44
30 150H STG 150 20 5 M	301	6.3	11922		"	"	12011	1.01
30 150H STG 150 25 5 M	302	10.2	13794		"	"	20410	1.48
30 150H STG 150 30 5 M	303	12.8	13794		"	"	27208	1.97
30 150H STG 150 35 5 M	304	11.2	13794		"	"	24942	1.81
30 150H STG 150 40 5 M	305	12.3	15573		"	"	24942	1.60
30 150H STG 200 20 5 M	306	6.5	8941		"	"	13592	1.52
30 150H STG 200 25 5 M	307	8.0	10344		"	"	15894	1.54
30 150H STG 200 30 5 M	308	11.9	10344		"	"	24942	2.41
30 150H STG 200 35 5 M	309	11.2	10344		"	"	22674	2.19
30 150H STG 200 40 5 M	310	11.4	11679		"	"	22674	2.19
30 150H STG 250 25 5 M	312	6.2	8813		"	"	11334	1.29
30 150H STG 250 30 5 M	313	7.2	8813		"	"	13592	1.54
30 150H STG 250 35 5 M	314	8.4	8813		"	"	15894	1.80

Table 23 Benefit Cost Ratios of New Systems

SYSTEM CODE	CASE NO.	VI <sub>15</sub>	COSTS (\$/mi/yr)	AREA (TYPE)	DENSITY (People/sq mi)	VOLUME (ADT)	BENEFITS (\$/mi/yr)	BENEFIT COST RATIO
30 150H STG 250 40 5 M	315	9.3	9949		30000	20000	18152	1.82
30 175M SS 50 30 5 M	358	10.1	17624		"	"	20410	1.16
30 175M SS 50 35 5 M	359	10.7	17624		"	"	22674	1.29
30 175M SS 50 40 5 M	360	10.4	20095		"	"	20410	1.02
30 175M SS 100 30 5 M	363	6.4	8989		"	"	11334	1.26
30 175M SS 100 35 5 M	364	7.1	8989		"	"	13592	1.51
30 175M SS 100 40 5 M	365	7.1	10249		"	"	13592	1.33
30 175M SS 150 35 5 M	369	3.8	6344		"	"	6366	1.00
30 175M SS 150 40 5 M	370	4.5	7234		"	"	9076	1.25
30 175M STG 100 35 5 M	404	9.7	17976		"	"	20410	1.14
30 175M STG 100 40 5 M	405	10.1	20497		"	"	20636	1.01
30 175M STG 150 30 5 M	408	6.8	12689		"	"	13140	1.04
30 175M STG 150 35 5 M	409	7.6	12689		"	"	15894	1.25



Table 24 Summary of New Systems

OPTIONS (SYSTEM CODE)	CASE NO.	VI T5	ENERGY USE (kwh/mi yr) x10 <sup>2</sup>	INITIAL COSTS		ANNUAL COSTS (\$/mi/yr)		TOTAL ANNUAL COSTS (\$/mi/yr)	AREA TYPE	DENSITY (People/ Sq. mi.)	VOLUME (ADT)	ACCIDENT REDUCTION (%)	BENEFITS (\$/mi/yr)	BENEFIT COST RATIO
				TOTAL (\$/mi)	ANNUAL (\$/mi/yr)	MAIN- TENANCE	ENERGY							
60/400M/STG/100/35/11/M	23	13.4	1704	98040	10563	752	15228	26543	CBD	30000	20000	40	27208	1.03
60/400M/STG/100/40/11/M	24	13.8	1704	120960	13084	752	15228	29043	CBD	"	"	44	29476	1.02
60/400M/STG/100/45/11/M	25	13.8	1704	120960	13084	752	15228	29043	CBD	"	"	44	29476	1.02
60/400M/STG/150/45/11/M	30	10.7	1147	85383	9235	530	10749	20514	CBD	"	"	34	21995	1.07
60/400M/STG/200/45/11/M	35	7.8	852	64038	6927	398	8062	15387	CBD	"	"	24	15434	1.00
30/400M/SS/50/35/5/M	43	13.1	1720	96118	10356	737	14929	26022	CBD	"	"	40	27208	1.05
30/400M/SS/50/40/5/M	44	13.9	1720	118588	12827	737	14929	28493	CBD	"	"	44	29476	1.03
30/400M/SS/50/45/5/M	45	14.1	1720	118588	12827	737	14929	28493	CBD	"	"	44	29476	1.03
30/400M/SS/100/30/5/M	47	7.4	852	49020	5281	376	7614	13271	CBD	"	"	20	13592	1.02
30/400M/SS/100/35/5/M	48	9.1	852	49020	5281	376	7614	13271	CBD	"	"	27	18152	1.37
30/400M/SS/100/40/5/M	49	9.6	852	60480	6542	376	7614	14532	CBD	"	"	30	20410	1.40
30/400M/SS/100/45/5/M	50	9.8	852	60480	6542	376	7614	14532	CBD	"	"	30	20410	1.40
30/400M/SS/150/35/5/M	53	5.7	573	34602	3728	265	5374	9367	CBD	"	"	17	11334	1.21
30/400M/SS/150/40/5/M	54	6.5	573	42692	4618	265	5374	10257	CBD	"	"	20	13592	1.33
30/400M/SS/150/45/5/M	55	7.3	573	42692	4618	265	5374	10257	CBD	"	"	20	13592	1.33
30/400M/SS/200/40/5/M	59	4.4	426	32019	3463	199	4031	7693	CBD	"	"	10	7721	1.00
30/400M/SS/200/45/5/M	60	5.3	426	32019	3463	199	4031	7693	CBD	"	"	13	9076	1.18
30/400M/SS/250/45/5/M	65	3.9	344	27275	2950	170	3434	6554	CBD	"	"	10	6818	1.04
30/400M/OPP/100/30/5/M	67	12.8	1704	98040	10563	752	1704	26543	CBD	"	"	40	27208	1.03

Table 24 Summary of New Systems

OPTIONS (SYSTEM CODE)	CASE NO.	VI <sub>T5</sub>	ENERGY USE (kwh/mi yr) x10 <sup>2</sup>	INITIAL COSTS		ANNUAL COSTS (\$/mi/yr)		TOTAL COSTS ANNUAL (\$/mi/yr)	AREA TYPE	DENSITY (People/ Sq.mi.)	VOLUME (ADT)	ACCIDENT REDUCTION (%)	BENEFITS (\$/mi/yr)	BENEFIT COST RATIO
				TOTAL (\$/mi)	ANNUAL (\$/mi/yr)	MAIN- TENANCE	ENERGY							
30/400M/OPP/100/35/5/M	68	14.0	1704	98040	10563	752	15228	26543	CBD	30000	20000	44	29476	1.11
30/400M/OPP/100/40/5/M	69	14.7	1704	120960	13084	752	15228	29043	CBD	"	"	47	31740	1.09
30/400M/OPP/100/45/5/M	70	15.4	1704	120960	13084	752	15228	29043	CBD	"	"	47	31766	1.09
30/400M/OPP/150/45/5/M	75	10.8	1147	85383	9235	530	10749	20514	CBD	"	"	35	22220	1.08
30/400M/STG/100/25/5/M	86	15.2	1704	98040	10563	752	15228	26543	CBD	"	"	47	31753	1.20
30/400M/STG/100/30/5/M	87	16.3	1704	98040	10563	752	15228	26543	CBD	"	"	47	31822	1.20
30/400M/STG/100/35/5/M	88	16.3	1704	98040	10563	752	15228	26543	CBD	"	"	47	31822	1.20
30/400M/STG/100/40/5/M	89	16.3	1704	120960	13084	752	15228	29043	CBD	"	"	47	31822	1.10
30/400M/STG/100/45/5/M	90	16.2	1704	120960	13084	752	15228	29043	CBD	"	"	47	31816	1.10
30/400M/STG/150/30/5/M	92	11.0	1147	69205	7456	530	10749	18735	CBD	"	"	34	22674	1.21
30/400M/STG/150/35/5/M	93	12.3	1147	69205	7456	530	10749	18735	CBD	"	"	37	24942	1.33
30/400M/STG/150/40/5/M	94	13.0	1147	85383	9235	530	10749	20514	CBD	"	"	40	27208	1.33
30/400M/STG/150/45/5/M	95	13.2	1147	85383	9235	530	10749	20514	CBD	"	"	40	27208	1.33
30/400M/STG/200/35/5/M	98	9.0	852	51904	5592	398	8062	14052	CBD	"	"	27	18152	1.29
30/400M/STG/200/40/5/M	99	10.1	852	64038	6927	398	8062	15387	CBD	"	"	30	20410	1.33
30/400M/STG/200/45/5/M	100	10.7	852	64038	6927	398	8062	15387	CBD	"	"	34	22674	1.47
30/400M/STG/250/40/5/M	104	7.2	688	54550	5900	339	6867	13106	CBD	"	"	20	13592	1.04
30/400M/STG/250/45/5/M	105	8.3	688	54550	5900	339	6867	13106	CBD	"	"	24	15894	1.21
60/400H/OPP/100/25/11/M	106	16.0	1704	104599	11283	2548	15228	29059	CBD	"	"	47	31803	1.09

Table 24 Summary of New Systems

CASE NO.	OPTIONS (SYSTEM CODE)	VI IS	ENERGY USE (kwh/mi yr) x10 <sup>2</sup>	INITIAL COSTS (\$/mi)		ANNUAL COSTS (\$/mi/yr)		TOTAL COSTS ANNUAL (\$/mi/yr)	AREA TYPE	DENSITY (People/Sq.mi.)	VOLUME (ADT)	ACCIDENT REDUCTION (%)	BENEFITS (\$/mi/yr)	BENEFIT COST RATIO
				TOTAL (\$/mi)	ANNUAL (\$/mi/yr)	MAINTENANCE (\$/mi/yr)	ENERGY (\$/mi/yr)							
107	60/400H/OPP/100/30/11/M	17.7	1704	104589	11283	2548	15228	29059	CBD	30000	20000	47	31911	1.10
108	60/400H/OPP/100/35/11/M	17.7	1704	104589	11283	2548	15228	29059	CBD	"	"	47	31911	1.10
109	60/400H/OPP/100/40/11/M	18.0	1704	127508	13804	2548	15228	31580	CBD	"	"	47	31930	1.01
110	60/400H/OPP/100/45/11/M	18.0	1704	127508	13804	2548	15228	31580	CBD	"	"	47	31930	1.01
113	60/400H/OPP/150/35/11/M	12.6	1147	73827	7964	1799	10749	20511	CBD	"	"	40	27208	1.33
114	60/400H/OPP/150/40/11/M	13.9	1147	90005	9744	1799	10749	22292	CBD	"	"	44	29476	1.32
115	60/400H/OPP/150/45/11/M	14.7	1147	90005	9744	1799	10749	22292	CBD	"	"	47	31740	1.42
119	60/400H/OPP/200/40/11/M	8.5	852	67504	7308	1349	8062	16719	CBD	"	"	27	18152	1.09
120	60/400H/OPP/200/45/11/M	10.4	852	67504	7308	1349	8062	16719	CBD	"	"	30	20410	1.22
126	60/400H/STG/100/25/11/M	16.5	1704	104589	11283	2548	15228	29059	CBD	"	"	47	31835	1.10
127	60/400H/STG/100/30/11/M	19.1	1704	104589	11283	2548	15228	29059	CBD	"	"	47	32000	1.10
128	60/400H/STG/100/35/11/M	18.7	1704	104589	11283	2548	15228	29059	CBD	"	"	47	31975	1.10
129	60/400H/STG/100/40/11/M	18.2	1704	127508	13804	2548	15228	31580	CBD	"	"	47	31943	1.01
130	60/400H/STG/100/45/11/M	18.5	1704	127508	13804	2548	15228	31580	CBD	"	"	47	31962	1.01
132	60/400H/STG/150/30/11/M	13.1	1147	73827	7964	1799	10749	20511	CBD	"	"	40	27208	1.33
133	60/400H/STG/150/35/11/M	14.2	1147	73827	7964	1799	10749	20511	CBD	"	"	44	29476	1.44
134	60/400H/STG/150/40/11/M	15.0	1147	90005	9744	1799	10749	22292	CBD	"	"	47	31740	1.42
135	60/400H/STG/150/45/11/M	15.5	1147	90005	9744	1799	10749	22292	CBD	"	"	47	31772	1.43
137	60/400H/STG/200/30/11/M	8.2	852	55371	5973	1349	8062	15384	CBD	"	"	24	15894	1.03
138	60/400H/STG/200/35/11/M	10.9	852	55371	5973	1349	8062	15384	CBD	"	"	34	22674	1.47

Table 24 Summary of New Systems

OPTIONS (SYSTEM CODE)	CASE NO.	VI <sub>15</sub>	ENERGY USE (kwh/mi yr) x10 <sup>2</sup>	INITIAL COSTS		ANNUAL COSTS (\$/mi/yr)		TOT. L ANNUAL COSTS (\$/mi/yr)	AREA TYPE	DENSITY (People/ Sq.mi.)	VOLUME (ADT)	ACCIDENT REDUCTION (%)	BENEFITS (\$/mi/yr)	BENEFIT COST RATIO
				TOTAL (\$/mi)	ANNUAL (\$/mi/yr)	MAIN- TENANCE	ENERGY							
60/400H/STG/200/40/11/M	139	12.5	852	67504	7308	1349	8062	16719	CBD	30000	20000	40	27208	1.63
60/400H/STG/200/45/11/M	140	12.7	852	67504	7308	1349	8062	16719	CBD	"	"	40	27208	1.63
60/400H/STG/250/35/11/M	143	8.1	688	47167	5089	1149	6867	13105	CBD	"	"	24	15894	1.21
60/400H/STG/250/40/11/M	144	9.3	688	57504	6225	1149	6867	14241	CBD	"	"	27	18152	1.27
60/400H/STG/250/45/11/M	145	10.8	688	57504	6225	1149	6867	14241	CBD	"	"	34	22674	1.59
30/400H/SS/50/25/5/M	146	23.2	1720	102538	11062	2498	14929	28489	CBD	"	"	48	32260	1.32
30/400H/SS/50/30/5/M	147	22.6	1720	102538	11062	2498	14929	28489	CBD	"	"	48	32222	1.13
30/400H/SS/50/35/5/M	148	24.4	1720	102538	11062	2498	14929	28489	CBD	"	"	48	32336	1.14
30/400H/SS/50/40/5/M	149	24.2	1720	125008	13533	2498	14929	30960	CBD	"	"	48	32324	1.04
30/400H/SS/50/45/5/M	150	24.3	1720	125008	13533	2498	14929	30960	CBD	"	"	48	32330	1.04
30/400H/SS/100/25/5/M	151	13.0	852	52294	5642	1274	7614	14530	CBD	"	"	40	27208	1.87
30/400H/SS/100/30/5/M	152	15.0	852	52294	5642	1274	7614	14530	CBD	"	"	47	31740	2.18
30/400H/SS/100/35/5/M	153	16.6	852	52294	5642	1274	7614	14530	CBD	"	"	47	31842	2.19
30/400H/SS/100/40/5/M	154	16.9	852	63754	6902	1274	7614	15790	CBD	"	"	47	31860	2.02
30/400H/SS/100/45/5/M	155	17.1	852	63754	6902	1274	7614	15790	CBD	"	"	47	31873	2.02
30/400H/SS/150/25/5/M	156	6.1	573	36914	3982	899	5374	10255	CBD	"	"	17	11334	1.11
30/400H/SS/150/30/5/M	157	9.8	573	36914	3982	899	5374	10255	CBD	"	"	30	20410	1.99
30/400H/SS/150/35/5/M	158	11.5	573	36914	3982	899	5374	10255	CBD	"	"	37	24942	2.43
30/400H/SS/150/40/5/M	159	12.9	573	45003	4872	899	5374	11145	CBD	"	"	40	27208	2.44

Table 24 Summary of New Systems

OPTIONS (SYSTEM CODE)	CASE NO.	VI <sub>15</sub>	ENERGY USE (kwh/mi yr) x10 <sup>2</sup>	INITIAL COSTS		ANNUAL COSTS (\$/mi/yr)		TOTAL ANNUAL COSTS (\$/mi/yr)	AREA TYPE	DENSITY (People/ Sq.mi.)	VOLUME (ADT)	ACCIDENT REDUCTION (%)	BENEFITS (\$/mi/yr)	BENEFIT COST RATIO
				TOTAL (\$/mi)		MAIN- TENANCE	ENERGY							
30/400H/SS/150/45/5/M	160	13.5	573	45003	4872	899	5374	11145	CBD	30000	20000	44	29476	2.64
30/400H/SS/200/35/5/M	163	6.2	426	27685	2987	674	4031	7692	CBD	"	"	17	11334	1.47
30/400H/SS/200/40/5/M	164	8.1	426	33752	3654	674	4031	8359	CBD	"	"	24	15894	1.90
30/400H/SS/200/45/5/M	165	9.5	426	33752	3654	674	4031	8359	CBD	"	"	30	20410	2.44
30/400H/SS/250/45/5/M	170	5.8	344	28752	3113	575	3434	7122	CBD	"	"	17	11334	1.59
30/400H/OPP/100/25/5/M	171	24.6	1704	104589	11283	2548	15228	29059	CBD	"	"	48	32349	1.11
30/400H/OPP/100/30/5/M	172	25.6	1704	104589	11283	2548	15228	29059	CBD	"	"	48	32413	1.12
30/400H/OPP/100/35/5/M	173	25.8	1704	104589	11283	2548	15228	29059	CBD	"	"	48	32426	1.16
30/400H/OPP/100/40/5/M	174	25.5	1704	127508	13804	2548	15228	31580	CBD	"	"	48	32407	1.03
30/400H/OPP/100/45/5/M	175	24.7	1704	127508	13804	2548	15228	31580	CBD	"	"	48	32356	1.02
30/400H/OPP/150/30/5/M	177	12.8	1147	73827	7964	1799	10749	20511	CBD	"	"	40	27208	1.32
30/400H/OPP/150/35/5/M	178	15.9	1147	73827	7964	1799	10749	20511	CBD	"	"	47	31797	1.55
30/400H/OPP/150/40/5/M	179	17.5	1147	90005	9744	1799	10749	22292	CBD	"	"	47	31898	1.43
30/400H/OPP/150/45/5/M	180	17.9	1147	90005	9744	1799	10749	22292	CBD	"	"	47	31924	1.43
30/400H/OPP/200/40/5/M	184	10.1	852	67504	7308	1349	8062	16719	CBD	"	"	30	20410	1.22
30/400H/OPP/200/45/5/M	185	12.4	852	67504	7308	1349	8062	16719	CBD	"	"	37	24942	1.49
30/400H/ST6/100/25/5/M	191	27.7	1704	104589	11283	2548	15228	29059	CBD	"	"	48	32546	1.12
30/400H/ST6/100/30/5/M	192	28.7	1704	104589	11283	2548	15228	29059	CBD	"	"	49	32610	1.12
30/400H/ST6/100/35/5/M	193	27.2	1704	104589	11283	2548	15228	29059	CBD	"	"	48	32514	1.12
30/400H/ST6/100/40/5/M	194	25.7	1704	127508	13804	2548	15228	31580	CBD	"	"	48	32419	1.03

Table 24 Summary of New Systems

OPTIONS (SYSTEM CODE)	CASE NO.	VI <sub>15</sub>	ENERGY USE (kwh/mi yr) x10 <sup>2</sup>	INITIAL COSTS		ANNUAL COSTS (\$/mi/yr)		TOTAL COSTS ANNUAL (\$/mi/yr)	AREA TYPE	DENSITY (People/ Sq.mi.)	VOLUME (ADT)	ACCIDENT REDUCTION (%)	BENEFITS (\$/mi/yr)	BENEFIT COST RATIO
				TOTAL (\$/mi)	ANNUAL (\$/mi/yr)	MAINT- TENANCE	ENERGY							
30/400H/STG/100/45/5/M	195	24.7	1704	127508	13804	2548	15228	31586	CBD	30000	20000	48	32356	1.02
30/400H/STG/150/25/5/M	196	19.4	1147	73827	7964	1799	10749	20511	CBD	"	"	47	32019	1.56
30/400H/STG/150/30/5/M	197	20.2	1147	73827	7964	1799	10749	20511	CBD	"	"	48	32070	1.56
30/400H/STG/150/35/5/M	198	20.2	1147	73827	7964	1799	10749	20511	CBD	"	"	48	32070	1.56
30/400H/STG/150/40/5/M	199	20.6	1147	90005	9744	1799	10749	22292	CBD	"	"	48	32095	1.44
30/400H/STG/150/45/5/M	200	20.5	1147	90005	9744	1799	10749	22292	CBD	"	"	48	32089	1.44
30/400H/STG/200/25/5/M	201	12.9	852	55371	5973	1349	8062	15384	CBD	"	"	40	27208	1.77
30/400H/STG/200/30/5/M	202	15.9	852	55371	5973	1349	8062	15384	CBD	"	"	47	31797	2.07
30/400H/STG/200/35/5/M	203	16.7	852	55371	5973	1349	8062	15384	CBD	"	"	47	31848	2.07
30/400H/STG/200/40/5/M	204	16.8	852	67504	7308	1349	8062	16719	CBD	"	"	47	31854	1.91
30/400H/STG/200/45/5/M	205	17.0	852	67504	7308	1349	8062	16719	CBD	"	"	47	31867	1.91
30/400H/STG/250/25/5/M	206	7.3	688	47167	5089	1149	6867	13105	CBD	"	"	20	13592	1.03
30/400H/STG/250/30/5/M	207	11.9	688	47167	5089	1149	6867	13105	CBD	"	"	37	24942	1.90
30/400H/STG/250/35/5/M	208	13.8	688	47167	5089	1149	6867	13105	CBD	"	"	44	29476	2.25
30/400H/STG/250/40/5/M	209	14.7	688	57504	6225	1149	6867	14241	CBD	"	"	47	31740	2.23
30/400H/STG/250/45/5/M	210	15.3	688	57504	6225	1149	6867	14241	CBD	"	"	47	31740	2.23
60/150H/OPP/100/20/11/M	211	10.1	639	80491	8632	2548	5709	16889	CBD	"	"	30	20410	1.21
60/150H/OPP/100/25/11/M	212	11.4	639	104589	11293	2548	5709	19540	CBD	"	"	34	22674	1.16
60/150H/OPP/100/30/11/M	213	13.2	639	104589	11283	2548	5709	19540	CBD	"	"	40	27208	1.39

Table 24 Summary of New Systems

OPTIONS (SYSTEM CODE)	CASE NO.	VI <sub>15</sub>	ENERGY USE (kwh/mi yr) x10 <sup>2</sup>	INITIAL COSTS		ANNUAL COSTS (\$/mi/yr)		TOTAL COSTS ANNUAL (\$/mi/yr)	AREA TYPE	DENSITY (People/ Sq.mi.)	VOLUME (ADT)	ACCIDENT REDUCTION (%)	BENEFITS (\$/mi/yr)	BENEFIT COST RATIO
				TOTAL (\$/mi)	ANNUAL (\$/mi/yr)	MAIN- TENANCE	ENERGY							
60/150H/OPP/100/35/11/M	214	13.5	6.39	104589	11283	2548	5709	19540	CBD	30000	20000	44	29476	1.51
60/150H/OPP/100/40/11/M	215	13.5	6.39	109387	13804	2548	5709	22061	CBD	"	"	44	29476	1.34
60/150H/OPP/150/30/11/M	218	8.0	4.30	73827	7965	1799	4030	13794	CBD	"	"	24	15894	1.15
60/150H/OPP/150/35/11/M	219	8.9	4.30	73827	7965	1799	4030	13794	CBD	"	"	27	18152	1.32
60/150H/OPP/150/40/11/M	220	9.8	4.30	77214	9744	1799	4030	15573	CBD	"	"	30	20410	1.31
60/150H/OPP/200/35/11/M	224	6.2	3.19	56991	5973	1349	3022	10344	CBD	"	"	17	11334	1.10
60/150H/OPP/200/40/11/M	225	7.2	3.19	57911	7308	1349	3022	11679	CBD	"	"	20	13592	1.16
60/150H/STG/100/20/11/M	231	10.6	6.39	80491	8632	2548	5709	16889	CBD	"	"	34	22674	1.34
60/150H/STG/100/25/11/M	232	11.9	6.39	104589	11283	2548	5709	19540	CBD	"	"	37	24942	1.28
60/150H/STG/100/30/11/M	233	13.1	6.39	104589	11283	2548	5709	19540	CBD	"	"	40	27208	1.39
60/150H/STG/100/35/11/M	234	13.8	6.39	104589	11283	2548	5709	19540	CBD	"	"	44	29476	1.51
60/150H/STG/100/40/11/M	235	13.2	6.39	109387	13804	2548	5709	22061	CBD	"	"	40	27208	1.23
60/150H/STG/150/25/11/M	237	7.1	4.30	73827	7965	1799	4030	13794	CBD	"	"	20	13822	1.00
60/150H/STG/150/30/11/M	238	8.8	4.30	73827	7965	1799	4030	13794	CBD	"	"	27	18152	1.32
60/150H/STG/150/35/11/M	239	9.2	4.30	73827	7965	1799	4030	13794	CBD	"	"	27	18152	1.32
60/150H/STG/150/40/11/M	240	10.3	4.30	77214	9744	1799	4030	15573	CBD	"	"	30	20410	1.31
60/150H/STG/200/30/11/M	243	6.3	3.19	56991	5973	1349	3022	10344	CBD	"	"	17	11334	1.10
60/150H/STG/200/35/11/M	244	6.9	3.19	56991	5973	1349	3022	10344	CBD	"	"	20	13592	1.31
60/150H/STG/200/40/11/M	245	8.0	3.19	57911	7308	1349	3022	11679	CBD	"	"	24	15894	1.36
60/150H/STG/250/30/11/M	248	4.8	2.58	48547	5089	1149	2575	8813	CBD	"	"	13	9076	1.03

Table 24 Summary of New Systems

OPTIONS (SYSTEM CODE)	CASE NO.	VI <sub>15</sub>	ENERGY USE (kwh/mi yr) x10 <sup>2</sup>	INITIAL COSTS		ANNUAL COSTS (\$/mi/yr)		TOTAL COSTS ANNUAL (\$/mi/yr)	AREA TYPE	DENSITY (People/ Sq. mi.)	VOLUME (ADT)	ACCIDENT REDUCTION (%)	BENEFITS (\$/mi/yr)	BENEFIT COST RATIO
				TOTAL (\$/mi)	ANNUAL (\$/mi/yr)	MAINT- TENANCE	ENERGY							
60/150H/SS/250/35/11/M	249	5.4	258	48547	5089	1149	2575	8813	CBD	30000	20000	13	9076	1.03
60/150H/SS/250/40/11/M	250	6.8	258	49331	6225	1149	2575	9949	CBD	"	"	20	13592	1.37
30/150H/SS/50/20/5/M	251	9.1	644	78913	8463	2498	5597	16558	CBD	"	"	27	18152	1.10
30/150H/SS/50/25/5/M	252	11.4	644	102538	11062	2498	5597	19157	CBD	"	"	34	22674	1.18
30/150H/SS/50/30/5/M	253	13.0	644	102538	11062	2498	5597	19157	CBD	"	"	40	27208	1.42
30/150H/SS/50/35/5/M	254	13.2	644	102538	11062	2498	5597	19157	CBD	"	"	40	27208	1.42
30/150H/SS/50/40/5/M	255	13.6	644	107242	13533	2498	5597	21628	CBD	"	"	44	29476	1.36
30/150H/SS/100/20/5/M	256	6.3	319	40246	4316	1274	2854	8444	CBD	"	"	17	11334	1.34
30/150H/SS/100/25/5/M	257	8.6	319	52294	5642	1274	2854	9769	CBD	"	"	27	18152	1.86
30/150H/SS/100/30/5/M	258	10.7	319	52294	5642	1274	2854	9769	CBD	"	"	34	22674	2.32
30/150H/SS/100/35/5/M	259	11.0	319	52294	5642	1274	2854	9769	CBD	"	"	34	22674	2.32
30/150H/SS/100/40/5/M	260	10.6	319	54693	6902	1274	2854	11030	CBD	"	"	34	22674	2.06
30/150H/SS/150/20/5/M	261	4.1	215	28409	3047	899	2015	5961	CBD	"	"	10	6818	1.14
30/150H/SS/150/30/5/M	263	7.3	215	36914	3982	899	2015	6896	CBD	"	"	20	13592	1.97
30/150H/SS/150/35/5/M	264	6.4	215	36914	3982	899	2015	6896	CBD	"	"	17	11334	1.64
30/150H/SS/150/40/5/M	265	7.7	215	38607	4872	899	2015	7786	CBD	"	"	24	15894	2.04
30/150H/SS/200/30/5/M	268	4.8	160	27685	2987	674	1511	5172	CBD	"	"	13	9076	1.75
30/150H/SS/200/35/5/M	269	6.0	160	27685	2987	674	1511	5172	CBD	"	"	17	11334	2.19
30/150H/SS/200/40/5/M	270	6.4	160	28955	3653	674	1511	5838	CBD	"	"	17	11334	1.94

Table 24 Summary of New Systems

OPTIONS (SYSTEM CODE)	CASE NO.	VI <sub>15</sub>	ENERGY USE (kwh/mi yr) x10 <sup>2</sup>	INITIAL COSTS		ANNUAL COSTS (\$/mi/yr)		TOTAL COSTS ANNUAL (\$/mi/yr)	AREA TYPE	DENSITY (People/ Sq.mi.)	VOLUME (ADT)	ACCIDENT REDUCTION (%)	BENEFITS (\$/mi/yr)	BENEFIT COST RATIO
				TOTAL (\$/mi)	ANNUAL (\$/mi/yr)	MAINTENANCE	ENERGY							
30/150H/SS/250/30/5/M	273	3.6	129	23584	2544	575	1287	4406	CBD	30000	20000	10	6818	1.55
30/150H/SS/250/35/5/M	274	3.7	129	23584	2544	575	1287	4406	CBD	"	"	10	6818	1.55
30/150H/SS/250/40/5/M	275	4.4	129	24666	3113	575	1287	4975	CBD	"	"	10	6818	1.37
30/150H/OPP/100/20/5/M	276	13.7	639	80491	8632	2548	5709	16889	CBD	"	"	44	29476	1.75
30/150H/OPP/100/25/5/M	277	14.7	639	104589	11283	2548	5709	19540	CBD	"	"	47	31740	1.62
30/150H/OPP/100/30/5/M	278	16.0	639	104589	11283	2548	5709	19540	CBD	"	"	47	31803	1.63
30/150H/OPP/100/35/5/M	279	16.3	639	104589	11283	2548	5709	19540	CBD	"	"	47	31822	1.63
30/150H/OPP/100/40/5/M	280	15.6	639	109387	13804	2548	5709	22061	CBD	"	"	47	31778	1.44
30/150H/OPP/150/25/5/M	282	8.8	430	73827	7965	1799	4030	13794	CBD	"	"	27	18152	1.32
30/150H/OPP/150/30/5/M	283	10.4	430	73827	7965	1799	4030	13794	CBD	"	"	30	20410	1.48
30/150H/OPP/150/35/5/M	284	11.9	430	73827	7965	1799	4030	13794	CBD	"	"	37	24942	1.81
30/150H/OPP/150/40/5/M	285	13.2	430	77214	9744	1799	4030	15573	CBD	"	"	40	27208	1.75
30/150H/OPP/200/30/5/M	288	6.8	319	56991	5973	1349	3022	10344	CBD	"	"	20	13592	1.31
30/150H/OPP/200/35/5/M	289	8.3	319	56991	5973	1349	3022	10344	CBD	"	"	24	15894	1.54
30/150H/OPP/200/40/5/M	290	6.6	319	57911	7308	1349	3022	11679	CBD	"	"	20	13592	1.16
30/150H/OPP/250/30/5/M	293	5.3	258	48547	5089	1149	2575	8813	CBD	"	"	13	9076	1.03
30/150H/OPP/250/35/5/M	294	6.0	258	48547	5089	1149	2575	8813	CBD	"	"	17	11334	1.29
30/150H/OPP/250/40/5/M	295	5.9	258	49331	6225	1149	2575	9949	CBD	"	"	17	11334	1.14
30/150H/STG/100/20/5/M	296	13.6	639	80491	8632	2548	5709	16889	CBD	"	"	44	29476	1.75
30/150H/STG/100/25/5/M	297	16.4	639	104589	11283	2548	5709	19540	CBD	"	"	47	31829	1.63

Table 24 Summary of New Systems

OPTIONS (SYSTEM CODE)	CASE NO.	VI <sub>15</sub>	ENERGY USE (kwh/mi yr) x10 <sup>2</sup>	INITIAL COSTS		ANNUAL COSTS (\$/mi/yr)		TOTAL COSTS ANNUAL (\$/mi/yr)	AREA TYPE	DENSITY (People/ Sq.mi.)	VOLUME (ADT)	ACCIDENT REDUCTION (%)	BENEFITS (\$/mi/yr)	BENEFIT COST RATIO
				TOTAL (\$/mi)	ANNUAL (\$/mi/yr)	MAINT- TENANCE	ENERGY							
30/150H/STG/100/30/5/M	298	16.4	639	104589	11283	2548	5709	19540	CBD	30000	20000	47	31829	1.63
30/150H/STG/100/35/5/M	299	16.2	639	104589	11283	2548	5709	19540	CBD	"	"	47	31816	1.63
30/150H/STG/100/40/5/M	300	15.0	639	109387	13904	2548	5709	22061	CBD	"	"	47	31740	1.44
30/150H/STG/150/20/5/M	301	6.3	430	56817	6093	1799	4030	11922	CBD	"	"	17	12011	1.01
30/150H/STG/150/25/5/M	302	10.2	430	73827	7965	1799	4030	13794	CBD	"	"	30	20410	1.48
30/150H/STG/150/30/5/M	303	12.8	430	73827	7965	1799	4030	13794	CBD	"	"	40	27208	1.97
30/150H/STG/150/35/5/M	304	11.2	430	73827	7965	1799	4030	13794	CBD	"	"	34	24942	1.81
30/150H/STG/150/40/5/M	305	12.3	430	77214	9744	1799	4030	15573	CBD	"	"	37	24942	1.60
30/150H/STG/200/20/5/M	306	6.5	319	42613	4570	1349	3022	8941	CBD	"	"	20	13592	1.52
30/150H/STG/200/25/5/M	307	8.0	319	56991	5973	1349	3022	10344	CBD	"	"	24	15894	1.54
30/150H/STG/200/30/5/M	308	11.9	319	56991	5973	1349	3022	10344	CBD	"	"	37	24942	2.41
30/150H/STG/200/35/5/M	309	11.2	319	56991	5973	1349	3022	10344	CBD	"	"	34	22674	2.19
30/150H/STG/200/40/5/M	310	11.4	319	57911	7308	1349	3022	11679	CBD	"	"	34	22674	2.19
30/150H/STG/250/25/5/M	312	6.2	258	48547	5089	1149	2575	8813	CBD	"	"	17	11334	1.29
30/150H/STG/250/30/5/M	313	7.2	258	48547	5089	1149	2575	8813	CBD	"	"	20	13592	1.54
30/150H/STG/250/35/5/M	314	8.4	258	48547	5089	1149	2575	8813	CBD	"	"	24	15894	1.80
30/150H/STG/250/40/5/M	315	9.3	258	49331	6225	1149	2575	9914	CBD	"	"	27	18152	1.82
30/175M/SS/50/30/5/M	358	10.1	753	96118	10356	737	6531	17624	CBD	"	"	30	20410	1.16
30/175M/SS/50/35/5/M	359	10.7	753	96118	10356	737	6531	17624	CBD	"	"	34	22674	1.29

Table 24 Summary of New Systems

[illegible]

Table 25. Lighting System Costs (\$) New Wood Poles  
(1 Mile (1.6km), one sided, using average cost figures)

SPACE*	HT	LUMINAIRE	WOOD POLE= BRACKET+ FOUNDATION+ POLE		LUMINAIRE		WIRING AERIAL		ENERGY/ POWER		MAIN- TENANCE	TOTAL COSTS	
			INIT	ANN	INIT	ANN	INIT	ANN	ENERGY	OTHER		INIT	ANN
50'	L	M 175	35,595	3915	13,320	1465	5227	523	1867	4664	737	54,142	13,171
50'	M	M 175	46,515	5116	13,320	1465	5227	523	1867	4664	737	65,062	14,372
50'	H	M 175	69,790	6907	13,320	1465	5227	523	1867	4664	737	88,337	16,163
50'	M	M 400	46,515	5116	13,320	1465	5227	523	4265	10,664	737	65,062	22,770
50'	H	M 400	62,790	6907	13,320	1465	5227	523	4265	10,664	737	81,337	24,561
50'	L	HPS 150	35,595	3915	19,740	2171	5227	523	1599	3998	2498	60,562	14,704
50'	M	HPS 150	46,515	5116	19,740	2171	5227	523	1599	3998	2498	71,482	15,905
50'	H	HPS 150	62,790	6907	19,740	2171	5227	523	1599	3998	2498	87,757	17,696
50'	M	HPS 400	46,515	5116	19,740	2171	5227	523	4265	10,664	2498	71,482	25,237
50'	H	HPS 400	62,790	6907	19,740	2171	5227	523	4265	10,664	2498	87,757	27,028

Factors for Other Systems

SPACING	ONE-SIDED	TWO-SIDED	STAGGERED
50'	Table 9	2.00	2.00
100'	.51	1.02	1.02
150'	.36	.72	.72
200'	.27	.54	.54
250'	.23	.46	.46

Note: For low or high calculations the following % changes are approximate:

low: -75% on all except energy/power, e/p = -50%

high = +150% on all except energy/power, e/p = +50%

\* 1m = 3.28 ft.

Table 25. Lighting System Costs (\$) - New Metal Poles  
(1 Mile - (1.6km), one sided, using average cost figures)

			METAL POLE = TRANSFORMER BASE + FOUNDATION + POLE		LUMINAIRE		WIRING UNDERGROUND		ENERGY/POWER		MAINTENANCE	TOTAL COSTS	
SPACE	HT	LUMINAIRE	INIT	ANN	INIT	ANN	INIT	ANN	ENERGY	OTHER	ANNUAL	INIT	ANN
50'	L	M -175	49,035	5394	13,320	1,465	10,138	898	1867	4664	737	72,493	15,025
50'	M	M -175	72,660	7993	13,320	1,465	10,138	898	1867	4664	737	96,118	17,624
50'	H	M -175	95,130	10,464	13,320	1,465	10,138	898	1867	4664	737	118,588	20,095
50'	M	M -400	72,660	7993	13,320	1,465	10,138	898	4265	10,664	737	96,118	26,022
50'	H	M -400	95,130	10,464	13,320	1,465	10,138	898	4265	10,664	737	118,588	28,483
50'	L	HPS-150	49,035	5394	19,740	2,171	10,138	898	1599	3998	2498	78,913	16,558
50'	M	HPS-150	72,660	7993	19,740	2,171	10,138	898	1599	3998	2498	102,538	19,157
50'	H	HPS-150	95,130	10,464	19,740	2,171	10,138	898	1599	3998	2498	107,242	21,628
50'	M	HPS-400	72,660	7993	19,740	2,171	10,138	898	4265	10,664	2498	102,538	28,489
50'	H	HPS-400	95,130	10,464	19,740	2,171	10,138	898	4265	10,664	2498	125,008	30,960

Factors for Other Systems

SPACING	ONE-SIDED	TWO-SIDED	STAGGERED
50'	Table 10	2.00	2.00
100'	.51	1.02	1.02
150'	.36	.72	.72
200'	.27	.54	.54
250'	.23	.46	.46

NOTE: For low or high calculations the following % changes are approximate:  
low: -75% on all except energy/power, e/p = -50%  
high = +150% on all except energy/power = +50%  
\* 1m = 3.28 ft.

Table 25. Lighting System Costs (\$) - Existing Wood Poles  
(1 Mile - (1.6km), one sided, using average cost figures)

SPACE*	HT	LUMINAIRE	EXISTING WOOD POLE = BRACKET		LUMINAIRE		ENERGY/POWER		MAINTENANCE		TOTAL	
			INIT	ANN	INIT	ANN	ENERGY	OTHER	ANN		INIT	ANN
50'	L	M -175	6825	410	13,320	1465	1867	4664	737		20,145	9143
50'	M	M -175	6825	410	13,320	1465	1867	4664	737		20,145	9143
50'	H	M -175	6825	410	13,320	1465	1867	4664	737		20,145	9143
50'	M	M -400	6825	410	13,320	1465	4265	10,664	737		20,145	17,541
50'	H	M -400	6825	410	13,320	1465	4265	10,664	737		20,145	17,541
50'	L	HPS-150	6825	410	19,740	2171	1599	3998	2498		26,565	10,676
50'	M	HPS-150	6825	410	19,740	2127	1599	3998	2498		26,565	10,676
50'	H	HPS-150	6825	410	19,740	2127	1599	3998	2498		26,565	10,676
50'	M	HPS-400	6825	410	19,740	2127	4265	10,664	2498			20,008
50'	H	HPS-400	6825	410	19,740	2127	4265	10,664	2498		26,565	20,008

Factors for Other Systems

SPACING	ONE-SIDED	TWO-SIDED	STAGGERED
50'	Table 11	2.00	2.00
100'	.51	1.02	1.02
150'	.36	.72	.72
200'	.27	.54	.54
250'	.23	.46	.46

NOTE: For low or high calculations the following % changes are approximate:  
low: -75% on all except energy/power, e/p= -50%  
high =+150% on all except energy/power, e/p = +50%  
\* 1m = 3.28 ft.

## APPENDIX B

### Worksheets For New Lighting Systems

This appendix contains six worksheets which can be used in conjunction with the methodology in Section 3 of this guide to select lighting systems for urban arterial streets. It is suggested that the prospective user make copies as needed for each use of this guide and retain the originals for further use.

# Worksheet #1

Table 26 VI<sub>15</sub> vs. System Descriptions[illegible]

## Worksheet #2

Table 27 Costs of New Systems

[illegible]

Table 28 Benefits of New Systems

AREA TYPE	C B D						OTHER					
	10,000	20,000	30,000	40,000	50,000	60,000	10,000	20,000	30,000	40,000	50,000	60,000
VI <sub>15</sub> D*												
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
11												
12												
13												
14												
15												

APPLY FACTOR FOR VOLUME CHANGE

5,000	10,000	15,000	20,000	25,000
0.5	1.0	1.5	2.0	2.5

\* = Density in people  
per square mile

## Worksheet #4

Table 29 Benefit Cost Ratios of New Systems

[illegible]

## Worksheet #5

Table 30 Summary of New Systems

[illegible]

## APPENDIX C

### Worksheets For Upgraded Lighting Systems

This appendix contains five worksheets which can be used in conjunction with the methodology in Section 4 of this guide to select upgraded lighting systems for urban arterial streets. It is suggested that prospective users make copies as needed for each use of this guide and retain the originals for further use.

## Worksheet #6

Table 31 VI<sub>15</sub> vs. System Descriptions[illegible]

## Worksheet #7

### Table 32 Costs of Upgraded Systems

165.

## Worksheet #8

### Table 33 Benefits of Upgraded Systems

[illegible]

APPLY FACTOR FOR VOLUME CHANGE				
5,000	10,000	15,000	20,000	25,000
0.5	1.0	1.5	2.0	2.5

## Worksheet #9

Table 34 Benefit Cost Ratios of Upgraded Systems

[illegible]

## Worksheet #10

## Table 35 Summary of Upgraded Systems

[illegible]

Worksheet #11  
Table 36 Reduced Energy Options

[illegible]







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